

*PRELIMINARY DESIGN OF AN AEROBRAKE
FOR A LUNAR ORBITAL TO EARTH ORBITAL
CARGO TRANSPORT VEHICLE*

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GROUP # 11

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Abstract

Group 11 was assigned the project of designing an "aerobrake" structure that is to be used to reduce the fuel consumption of an orbital transport cargo vehicle (OTCV). The aerobrake's design should maximize the use of lunar materials and, if possible, be solely constructed from lunar materials. The principle of aerobraking is to build a device that when brought into a planetary atmosphere at high velocities, will dissipate the kinetic energy of the vehicle by viscous and shock irreversibilities (losses). Since these losses will convert the kinetic energy of the OTCV into thermal energy, the aerobrake must also shield the OTCV from these thermal effects.

By utilizing an aerobrake to slow the OTCV from high velocities down to orbital velocities, the OTCV will not need to expend large quantities of fuel for this same purpose. This will result in a more fuel efficient OTCV.

The following report will discuss in detail the proposed solution.

PROBLEM STATEMENT

The purpose of this research project is to design an aerobrake system for a hypothetical cargo carrying vehicle. This vehicle is to be used to transport processed materials from lunar orbit to low earth orbit. The major constraint on this design will be to use as many lunar materials as possible. In addition, any non-lunar materials should be reusable, so as to amortize their cost over as many missions as possible.

Because this is a cargo vehicle rather than a manned vehicle, economy of design will, for the most part, dictate the orbital profile. Also, the number of passes through the atmosphere that the vehicle will make will be left as a variable. The materials chosen for the aerobrake will be selected from materials that can logically be expected to be by products of the lunar mining colony. The complexity of the manufacturing process will be kept to a minimum.

The following assumptions will be made. The vehicle will be assembled in lunar orbit or on the moon's surface. The vehicle will be designed with a limited ability to change direction and velocity, but the guidance mechanisms will not be specified. The design of the aero-brake will be specified exactly, as well as possible manufacturing processes, but the vehicle will only be roughly outlined. This is so that the aerobrake is not restricted to one specific vehicle.

OVERVIEW OF EXISTING METHODOLOGY

This particular project has a good basis in theoretical and experimental fact, but to date no similar project has actually been undertaken. All of the designs that have been built so far have radically different goals.

The only existing proposals that, were found, had to do with vehicles making the GEO to LEO transfer. This would be a similiar flight regime, but would involve smaller payloads and lower velocity orbits. Many of the techniques discused in this paper are analogous to ones proposed for such a vehicle.

DESIGN OVERVIEW

The design that was chosen for this study consists of two major components; the supporting structure and the ceramic cloth shield that forms the front surface. This particular design was decided on because of its simplicity and ease of construction.

The overall shape of the aerobrake is that of a blunt spherical section. This shape was chosen because of the relatively less complicated aerodynamic analysis involved. The supporting structure is a geodesic framework. The orbital transfer vehicle is attached to the framework, and the ceramic cloth is attached across the front of the framework.

DESIGN

ASSEMBLY

The assembly of this shield will be very basic due to its simplicity of design and low part-piece count.

The assembly of the dome would start with the central hexagonal cell and work outward in a symmetric manner. All struts will be permanently joined to the unions by using a proper adhesive. A silicon based adhesive would be a good adhesive; however, the final adhesive should be determined only after proper testing. A combination of expanding the union by application of heat, prior to permanent joining, to create a shrink fit may be necessary. However, this should also be determined in testing procedures.

After the dome has been completely assembled, the compression members will be assembled near the inside center of the dome (see exhibit 5). These members will be permanently joined to the center hole on the underside of the union, in a similar manner as the struts. The other end will be permanently joined to the mounting plate.

Finally, the tension members will be joined to the center of the last row of unions (along the perimeter of the dome). It will be necessary at this point to have a swivel to couple the ends of the tension members to the unions (see exhibit 5). Then the opposite end of the tension member will be permanently joined to the perimeter of the mounting plate (see exhibit 5).

Now that the supporting structure has been completely assembled, the cover can be joined to the structure. This will be done by properly placing the cover over the structure and pulling it tightly

across the structure. This can be accomplished by placing the structure on a fixture and applying mechanical tensioning devices about the perimeter of the dome. While the cover is in tension the cover material will be pulled back along the inside of the dome and secured by using cordage of the same ceramic fiber to tie the cover securely to the dome.

Due to the simplicity of design, and with the use of a cover tensioning fixture, the assembly of this aerobrake could easily be accomplished by one man. The ease of assembly will lend itself to the possibly primitive assembly practices that may be encountered on the lunar surface.

DISCUSSION OF MATERIALS

The material to be used for the heat shield must be thermally stable. The material must be strong enough to resist thermal shock, and must be strong enough to span the framework without any localized deformation. The shield must prevent a great deal of heat from being transferred to the structure behind it. It is desirable that the shield be made of as many lunar materials as possible.

The first choice for the material for the shield is an aluminoborosilicate ceramic fiber textile. The alumina, boria, and silica are available on the moon, and the textile will be made by typical fiberglass and textile processes, to be explained in the following section.

The material to be used for the structural elements must be lightweight, durable, and resistant to thermal shock. It is desirable that the elements be made from as many lunar materials as is feasible. The first choice for the construction materials is a composite material consisting of aluminoborosilicate fibers coated with a polyurethane resin. The composite will be formed into hollow rods of desirable dimensions, which are specified in the structural analysis section. The manufacturing process to be used is a filament winding procedure.

In the following sections, the materials for the shield and rods will be further explained and the manufacturing processes described.

HEAT SHIELD MATERIAL ANALYSIS

The shield will be made of an aluminoborosilicate ceramic textile fiber, which was chosen for several reasons. Its use limit is 2600°F , and it not expected that the vehicle will experience temperatures in this range. It has a large tensile strength of 250×10^3 psi. The thermal conductivity is low at five Btu-in/h-ft² - $^{\circ}\text{F}$. It is desirable to have a low thermal conductivity so that the heat will not be transferred to the back of the shield, and consequently, the structure. Figure 1 demonstrates the relationship between thermal conductivity and temperature. Figure 2 offers a summary of the characteristics of the cloth.

The textile cloth consists of continuous filament fibers with a composition of 62% alumina(Al_2O_3), 24% silica(SiO_2), and 14% boria(B_2O_3). The percentages indicate that, for example, if a one hundred poound batch of glass was desired from which to draw the fibers, the batch would consist of 62 pounds of alumina, 24 pounds of silica, and 14 pounds of boria. Each of the constituents for the glass batch is found on the moon, with alumina and silica abundant. Boria will be more difficult to find, but it also the smallest percentage of the batch.

Figure 3 lists the major minerals found in the lunar rocks that were retrieved by the Apollo XI astronauts. It is evident from this list that silica and alumina should relatively easy to obtain. Another study indicates that there is an abundance of feldspar, $\text{R}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$, which an excellent source of alumina. Studies indicate that it is of uniform condition and sufficient purity to be used for fiberglass.

Boria is more difficult to locate, but is found in lunar highland melt

rocks. It is particularly abundant in Low-An Anorthositic gabbro rocks. A mining team would have to study the geology of the moon in depth to determine whether it would be feasible to mine boria. If the mineral is not readily available, a substitution for the boria in the glass composition could be made based on the chemical reactions occurring in the glass. This possibility will not be covered in the scope of this paper, but it is a topic for further consideration.

At this point, a discussion of the purpose of each of the components of the glass batch is necessary. Silica is the most important constituent of the glass. Its purpose is to serve as a network former. The size of the silicon atom (4A) lends itself to be easily surrounded by four oxygen atoms. This tetrahedral arrangement forms chains and networks.

The alumina is not a glass former by itself, so it is known as an intermediate. Its main purpose in the glass batch being discussed is its high melting point. The melting point of alumina is 2050 C , and this property contributes to the thermal stability of the textile cloth. Alumina also reduces devitrification, or crystallization, and contributes to the durability of the glass.

The boria can serve as a network former in itself, but since it is present in such a small quantity, it serves as a network modifier instead. Boria reduces the melting point of the batch by breaking some of the strong Si-O bonds. Boria also reduces the thermal expansion.

MANUFACTURING PROCESSES

The manufacturing processes used to make the ceramic textile will be very similar to those processes that are used on the earth.

Exhibit 1 depicts the overall manufacturing process as it is conceived to appear on the moon. However, before the manufacturing begins, the materials must first be obtained from the lunar surface, which will be the mining operation's responsibility. The materials need to be in the most pure state that is possible, and more than likely, most of the raw materials will have to be refined.

Once the alumina, silica, and boria are obtained, they will each be placed in their respective bins so that a constant supply of the materials will be available in storage. The amounts of each material that must go into the glass batch will be predetermined based on the total amount of glass product that is desired. A computerized system will control the operation. The computer will weigh the amounts directly from the bin and release each constituent directly onto a conveyor belt. The materials will then be fed into a dry mixer for thorough mixing.

It is critical that the raw materials be thoroughly mixed in order to insure a homogenous glass melt. High quality, uniform fibers will be drawn as a result of a homogenous glass mixture.

The batch of dry raw materials will then be fed into a furnace to be melted. The temperature needed to melt the batch can be determined from the ternary phase diagram for the Al_2O_3 - SiO_2 - B_2O_3 system, which is pictured in Exhibit 2. The point for a composition of 62% alumina, 24% silica, and 14% boria is plotted on the diagram, and this point corresponds to a temperature of about 1700 C.

The energy to melt the batch will be obtained through a solar

concentrator, as seen in Exhibit 1. After the batch has been melted, the furnace will continue along a conveyor belt to a fining process. At this point, the bubbles in the melt will be removed. They must be removed or they can cause serious imperfections in the glass product. The bubbles result from gases that are released and become trapped between the particles as the glass melts. The time to complete the fining process depends on the amount and size of the bubbles. The velocity with which the bubbles rise to the surface may be determined by Stoke's equation:

$$V = [D g (d_s - d_l)] / (12 \eta)$$

where V = velocity

D = Diameter of the sphere

g = gravitational constant

d_s = density of the sphere (negligible)

d_l = density of the molten glass

η = viscosity of glass at melting temperature

After the fining process, which can be very slow, is completed, the molten glass is poured onto a casting belt with grooves in it to form rods. These rods will form as the glass continues to cool. These rods may then be saved in storage or be transported to the Earth, and the rest will be remelted in the fiberglass production. These rods can also be visually inspected for flaws.

The glass rods will then be placed in a melter and heated until the glass is completely melted. The process for forming fiberglass is illustrated in Exhibit 3. The glass will then flow through a platinum

bushing which contains at least 200 very small openings. The strand of multiple filaments is then carried to a high speed winder which revolves at about two miles, or three kilometers, per minute. Since this is a much faster rate than the rate at which molten glass flows from the melting chamber, the tension will attenuate the glass while it is still molten. The fibers will be drawn into parallel filaments to a fraction of the diameter of the openings. In this case, the final diameter of the fibers should be eleven microns.

A temporary binder may then be applied to prevent abrasion and breakage. The fibers are wound onto spools, and then designated for further processing. Some of the fiber will be woven into textile cloth, as depicted in Exhibit 4. A fairly standard weaving method will be employed. The fibers must be woven as tightly as possible in order to increase the durability of the cloth. The fabric will then be cut to the desired shape to be fitted onto the front of the structure.

Some of the spools of fiber will be reserved to make a composite for the structural elements. This procedure will be discussed in the next section.

ANALYSIS OF STRUCTURAL ELEMENT MATERIAL

The material to be used for the structural elements must be strong, resistant to thermal shock, and constructed from as many lunar materials as is practical. The weight must also be kept within reason.

A material that seems to meet these specifications is a glass fiber composite. The composite will consist of aluminoborosilicate fibers which will be coated with a polyurethane resin. Since these fibers would already be in production to make the ceramic fiber textile, it seemed most logical to use them in the composite. These fibers are also strong, durable, and able to withstand high temperatures, making them ideal for consideration for the structural elements.

The polyurethane resin is organic, and must therefore be brought from the earth. However, it seems to be more economical to transport a supply of resin than to establish more mining and melting operations to produce one specific composite. The resin would at most constitute 20% of the composite.

The major limitation of the polyurethane is that its maximum use temperature is 250 F. However, it is likely that the temperatures experienced by the structural components will not exceed this range. It is expected that the heat shield will absorb most of the heat and prevent it from being transferred to the back of the shield, and consequently, the structure.

As added insurance against any thermal stresses that might develop in the components of the structure, insulation will be placed around any rods suspected of being in areas prone to thermal failure. The insulation will be a ceramic fiber needle-felted blanket which will be shaped into tubes to be fitted over the structural rods. The composition of the fibers in the blanket is about 50% alumina and 50% silica, both of which are found on the moon. The blanket has a use limit of 1800 F , which is far above the temperatures expected to be experienced by the structure. Since the insulation is a secondary material which may not be needed at all, its manufacture will not be discussed here. The only method to determine the need for insulation is to run the aerobrake through one cycle and examine any thermal damage.

MATERIAL FOR STRUCTURAL ELEMENTS

The process to be used for forming the composite is known as filament winding. The continuous fibers will be run through a resin bath to be coated with polyurethane. The coated fibers will then be wound around a rotating mandrel until the desired thickness is attained. The composite will be cured while on the mandrel to allow polymerization to occur. The mandrel will then be removed.

The filament winding process was chosen because it produces products with a high strength -to-weight ratio and good impact resistance. At this point, the production of the composite rods will be discussed in more detail.

The apparatus used for the process is pictured in Exhibit 5. One of the first considerations is the winding mechanism. In order to produce a tube that will withstand great axial loads, the fibers should be wound in a helical pattern, as shown in detail in Exhibit 6. In this winding method, more of the fibers are oriented in the axial direction, thus strengthening the composite in the axial direction.

Exhibit 7 shows the winding process in detail. As shown in the picture, the carriage will traverse up and down the length of the shaft as the mandrel continues to rotate. These two movements determine the pattern in which the fibers are wound. The carriage will continue to move until the desired thickness is obtained.

Located on top of the carriage is the resin bath. The fibers are pulled through the polyurethane to be coated before they are wound around the mandrel.

The last treatment applied to the composite before its release from

the mandrel is curing. In this step, the resin coated fibers will be heat treated while on the mandrel so that polymerization will occur. During polymerization, strong fiber to fiber bonds form as a result of the polyurethane resin coating.

The exact curing temperature and time would have to be determined experimentally, since these parameters would vary depending on the reinforcement and resin that was used.

After polymerization has been completed, the composite is cooled, and the mandrel extracted. Upon release, the composite will have a tensile strength between 60,000 and 70,000 psi.

This manufacturing process could be totally computerized. The programming parameters are designated in Exhibit 5, and are labeled as follows: Band width (W); Winding angle (A); winding parameter (D); and home position (H). By adjusting these parameters, the qualities of the final product can be altered.

ALTERNATE MATERIALS

Two materials which can possibly serve as alternates to the glass fiber/organic resin composite will be discussed briefly in this section.

The first material to be considered is a glass/glass composite to be formed by the filament winding, as discussed in the previous section.

The glass fibers to be used in this case would be of the "C" glass composition, which is a universal glass composition. The glass is 63.6% SiO_2 , 3.8% Al_2O_3 , .2% Fe_2O_3 , 14% CaO , 2.6% MgO , 6.7% B_2O_3 , 8.7% BaO , and .4% K_2O . It is likely that the majority of these minerals can be located on the moon. If all are not available, then substitutions could be made for the minor constituents. This glass is advantageous because of its flexible composition. It is a durable and thermally stable glass, and would easily meet the requirements placed upon it by the structural elements.

Molten aluminoborosilicate glass would substitute for the resin in this case. Since the glass will already be in production, it will be readily available as a material to coat the glass fibers. However, the aluminoborosilicate glass must wet the fibers, and this should first be determined by experimentation.

The glass/glass composite is purely a suggestion based on prior knowledge of materials and processes. It would have to be further investigated to insure that it is a reasonable and feasible product for the structural elements.

A second alternate is alumina fibers in an alumina matrix. This composite would be very strong and heat resistant. However, it may be more than is required by the aerobrake. The temperatures and forces experienced by the aerobrake should be far below the use limits for alumina.

However, if the aerobrake did not behave as expected, an alumina composite would be a good choice. The process requires pure alumina fibers and liquid alumina. A common method to form the composite is known as squeeze casting. Preheated, preformed alumina fibers are inserted into a die, and liquid alumina is poured into the die cavity. A ram is inserted and pressure is applied in order to form the final shape.

The major limitations with this process are the high pressures that have to be applied and the limited range of shapes that can be formed. From the lunar aspect, it may be difficult to mine sufficient amounts of pure alumina to manufacture such a composite.

MATERIALS ANALYSIS

CONCLUSIONS:

After investigating the possibilities for the materials that meet the thermal and structural requirements of the aerobrake, it appears that the appropriate shield and structural elements can be made on the moon. The aluminoborosilicate fibers have excellent properties that can be utilized by the aerobrake. There is the potential for many glass compositions that can be made from lunar materials.

However, it must be noted that extensive tests would have to be conducted concerning the mining of the raw materials. If the processes that were discussed in the previous sections were to be used on the moon, extensive testing would have to be done on the products that result. An experimental aerobrake would have to be constructed and run through the full orbital cycle to determine the effects of temperature and force. After this testing was completed, the materials could be adjusted to meet any specifications that result from thermal or structural failure.

AERODYNAMIC ANALYSIS

To conduct an analysis of the aerodynamic forces on trajectories at orbital speeds, it is necessary to develop certain assumptions about the planetary atmosphere involved. Because of the nature of the forces, the atmospheric property that is of overriding importance for a spacecraft is the density. For this reason, to create a model of the physical forces on such a ship, it is necessary to develop a good model of atmospheric density.

There are several assumptions that must be made in order to simplify this problem. The first, and probably most important, is spherical atmospheric symmetry. With this assumption, the density is proportional only to the radial distance, r , from the center of the planet. Better yet is the assumption that the density depends only on altitude. This eliminates the problems associated with an unspherical planet. This does introduce an error, but the decrease in complexity is worth the small increase in error. Another source of error is the reaction of the atmosphere to solar activity. From reference 1 it can be seen that these effects are negligible below 250 km altitude. Considering the value of the density at that altitude, this is also a reasonable simplification.

Another important simplification is that the atmosphere is not rotating. For the Earth the effects of a rotating atmosphere are only important at low altitudes. For example, the maximum rotational speed of the atmosphere is about six percent of the circular orbital velocity at low altitude. Because this is so small, for reasonable approximations it can be ignored.

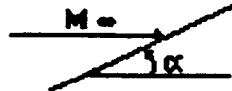
The final assumption is that the density can be modeled as a function that decreases exponentially with altitude. To make this

assumption accurate, the atmosphere must be broken down into segments that are small enough to give reasonable accuracy. Using the methods developed in reference 1 it is possible to model the atmospheric density between 54 km and 300 km with a maximum deviation from the 1959 ARDC model atmosphere of only 1.52%. This is the approach that is taken in the program ORBIT, that is listed in the computer programs section of this report.

Drag Analysis

For the configuration of our aerobrake, a fairly accurate drag estimation can be obtained by assuming a Newtonian flow. This model is well suited to analyzing hypersonic flow where the shock waves are so strong that the wave drag dominates any viscous forces. With this assumption, friction can be ignored. Thus, the drag coefficient does not depend on Reynolds number or altitude, but depends only on the geometry of the aerobrake, simplifying the problem a great deal. According to Newton's model:

$$C_p = C_p^* \sin^2 \alpha \quad \text{and} \quad C_D = C_p^* \sin^3 \alpha$$



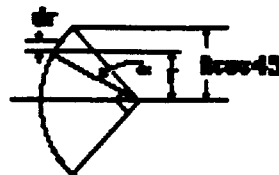
$$\text{where } C_p^* = \frac{2}{\gamma M^2} \left[\left(\frac{\gamma+1}{2} M^2 \right)^{\gamma/(\gamma-1)} \left(\frac{\gamma+1}{2\gamma M^2 - \gamma + 1} \right)^{1/(\gamma-1)} - 1 \right]$$

$$\text{since } M^2 \gg 1, \quad C_p^* = \frac{2}{\gamma} \left[\frac{(\gamma+1)^{\gamma/(\gamma-1)}}{2} \frac{(\gamma+1)^{1/(\gamma-1)}}{2\gamma} \right]$$

$$\text{and with } \gamma = 1.4 \quad C_p^* = 1.8386$$

Although the aerobrake is not truly spherical, it is safe to assume the spherical geometry because the areas of the vertices of the hexagon that lie outside of the assumed sphere are negligible compared to the sphere's surface area. Furthermore, since C_D is proportional to $\sin^3 \alpha$, C_D on these vertices is negligible as α decreases.

Thus we integrate local C_D over the projected frontal area:



$$\begin{aligned} r &= R \cos \alpha, \quad dr = -R \sin \alpha d\alpha \\ C_D R &= \int (C_p^* \sin^3 \alpha) (2\pi r) dr = 2\pi C_p^* \int_{\pi/4}^{\pi/2} \sin^3 \alpha (R \cos \alpha) (-R \sin \alpha) d\alpha \\ &= 2\pi C_p^* R^2 \sin^5 \alpha \Big|_{\pi/4}^{\pi/2} = 3.804 R^2 \\ C_D &= \frac{3.804 R^2}{\pi (R/\sqrt{2})^2} = 2.422 \end{aligned}$$

STRUCTURAL ANALYSIS

The structural analysis of the aerobrake will be divided into three distinct areas.

- 1) The structural integrity of the cover.
- 2) The structural integrity of the dome.
- 3) The structural integrity of the sub-frame.

These three sections will be further subdivided into a list of assumptions and a set of calculations. The assumptions will include the material of choice for the selected application and the calculations will be carried out using this material.

A computer program which is listed in the program section of this report can be used for further application.

COVER ANALYSIS

Assumptions:

- 1) Cover material: aluminoborosilicate ceramic fiber textile
- 2) Equilateral triangle size: 2.5 ft. leg
- 3) Fiber chord diameter: 0.048 in
- 4) Max pressure forces: 5 lb/in²

In this part of the analysis the minimum cover fiber density will be determined to insure that the cover material will withstand the pressure forces as it spans the triangular unit cell.

Since it has been determined from the aerodynamic analysis that the maximum pressure force that will be exerted on the front of the aerobrake is five p.s.i. , the total force that the cover material must withstand at each unit cell is:

$$F = P_{\max} A_T$$

Where A_T is the area of the equilateral triangle.

$$A_T = 1/2 bh = 1/2(2.50)(2.165)$$

$$A_T = 2.71 \text{ ft}^2$$

Now the total force per triangle can be calculated.

$$F = (5 \text{ psi}) (144 \text{ in}^2/\text{ft}^2) (2.71 \text{ ft}^2)$$

$$F = 1948.6 \text{ lbs/triangle}$$

Since the tensile strength of the ceramic fiber is 250,000 psi, then using a factor of safety of six, the allowable stress in each fiber will be given as:

$$\sigma_{\text{allow}} = \sigma_{\text{tensile}} / 6$$

$$\sigma_{\text{allow}} = 250,000 / 6 = 41,666.7 \text{ psi}$$

The combined area of all the fibers needed to cross the triangular area can be calculated as follows.

$$\text{FIBER AREA NEEDED} = F / \sigma_{\text{allow}}$$

$$\text{FIBER AREA NEEDED} = 1948.6 / 41,667 \text{ psi}$$

$$\text{FIBER AREA NEEDED} = .047 \text{ in}^2 / \text{cell}$$

At this time the cross-sectional area of one fiber must be calculated.

The given fiber diameter is 11 microns (4.331×10^{-4} in).

$$\text{SINGLE FIBER AREA} = AF = \pi(4.331 \times 10^{-4})^2 / 4$$

$$AF = 1.473 \times 10^{-7} \text{ in}^2$$

The number of fibers that are needed in an equilateral triangle cell area is:

$$\text{FIBER NUMBER} = \text{FIBER AREA PER CELL} / \text{AREA PER FIBER}$$

$$\text{FIBER NUMBER} = 0.47 \text{ in}^2 / 1.473 \times 10^{-7} \text{ in}^2$$

$$\text{FIBER NUMBER} = 3.175 \times 10^5 \text{ fibers}$$

The number of fibers that are in a 0.048 inch chord of ceramic fiber can be calculated as follows.

$$\text{FIBERS PER CHORD} = \text{AREA OF CHORD} / \text{AREA OF FIBER}$$

$$\text{FIBERS PER CHORD} = \pi(0.048)^2 / 4(1.473 \times 10^{-7})$$

$$\text{FIBERS PER CHORD} = 12,285 \text{ FIBERS} / (\text{CHORD} / \text{TRIANGLE})$$

Now the number of chords that are needed to span the triangular area can be calculated:

$$\text{CHORDS PER TRIANGLE} = \text{TOTAL \# OF FIBERS} / \text{\# OF FIBERS PER CHORD}$$

$$\text{CHORDS PER TRIANGLE} = 3.175 \times 10^5 / 12.285$$

$$\text{CHORDS PER TRIANGLE} = 25.8 \text{ CHORDS/TRIANGLE}$$

This means that within the woven fabric of the cover 1984 chords must traverse the unit triangle's area. This can be converted to chord density by:

$$\text{CHORD DENSITY} = \text{CHORDS PER TRIANGLE} / \text{AREA OF TRIANGLE}$$

$$\text{CHORD DENSITY} = 25.8/2.71$$

$$\text{CHORD DENSITY} = 9.54 \text{ CHORDS} / \text{ft}^2$$

This chord density is much lower than standard available woven cloths made of aluminaborosilicate fibers. Therefore, the standard double layer weave should withstand the forces due to aerobraking in this design.

DOME ANALYSIS

The forces that the dome will experience will be the result of a pressure difference, induced by the airflow across the structure. This pressure will act normal to the dome at all points; however, it will be greatest near the center.

This analysis will look at the worst case analogy. This would occur when the pressure is uniform over the whole dome, and equal to the maximum pressure developed in the system. This maximum pressure will be the stagnation pressure developed at the center of the dome and was calculated in the aerodynamic analysis to be approximately five psi.

By making this simplifying assumption, the analysis can be accomplished by examining a single hexagonal cell, since all other cells will react in a similar manner.

The hexagonal unit cell analysis will assume that all normal forces will be transferred down the struts, keeping them in compression.

This analysis will give conservative results for the diameter needed for the struts away from the geometric center of the dome. However, since it is beneficial to keep all struts identical, the hex unit at the center of the dome will exemplify the worst case, and thus will set the parameters for the rest of the structure.

UNIT HEX CELL ANALYSIS

The unit hex cell analysis will be primarily concerned with determining the approximate loading that each strut will experience.

Due to the nature of the loading, all struts will be in compression and will experience a bending moment due to a uniformly loaded normal force. Since the bending moment and compressive forces will tend to cause buckling of the strut the deflection due to this bending moment must be kept relatively small. Also, since the struts will be tubular in geometry, a two inch outside diameter (initial parameter) will be set and the inside diameter will be calculated (further calculations can be made if it is desired to change initial parameters by using program GEOBRK in program section of this report).

The compressive force will be calculated by first determining the force exerted over the area of one hex.

$$F_{\text{hex}} = (\text{pressure}) \times \text{Area}_{\text{hex}}$$

$$F_{\text{hex}} = (5)(144)(6 \times 1/2 (2.50)(2.165))$$

$$F_{\text{hex}} = 11,691 \text{ lbs}$$

Now the compressive force in each strut will be F_{hex} divided into each of the six central struts of the hex.

$$F_{\text{c,strut}} = 11,691 \text{ lbs} / 6 = 1949 \text{ lbs}$$

Since the material chosen for the strut application was an aluminoborosilicate composite with polyurethane matrix, the modulus of elasticity relative to the manufacturing process chosen is $E = 4 \times 10^6$ psi. From this, the load related to a condition of unstable equilibrium of the strut ($P_{critical}$) can be calculated using a factor of safety of four (large safety factor to help reduce effects of bending moment).

$$P_{cr} = nF_{(c, strut)}$$

$$P_{cr} = (4)(1949 \text{ lbf}) = 7794 \text{ lbf}$$

Now from this the inside diameter can be calculated.

$$\text{since } P_{cr} = C\pi^2 EI / L^2$$

$$\text{where } C = 1.2 \text{ (conservative fixed ends)}$$

$$E = 4 \times 10^6 \text{ psi}$$

$$I = \pi(d^4 - d_i^4) / 64$$

$$L = 2.5 \text{ ft} = 30 \text{ inches}$$

Now rearrange the above equation solving for d_i yields:

$$d_i = (d^4 - (64 P_{cr} L^2 / C\pi^3 E))^{1/4}$$

$$d_i = ((2.0)^4 - (64(7794 \text{ lbs})(30.0 \text{ in})^2 / 1.2\pi^3(4 \times 10^6)))^{1/4}$$

$$d_i = (16 - 3.0)^{1/4} = 1.898 \text{ inches}$$

Therefore the inside diameter can be approximated as 1.75 inches. Now the deflection of this strut should be examined. The strut will be modeled as a uniformly loaded beam. Now the force per inch of beam must be determined. In order to do this, the force per unit equilateral triangle must be calculated:

$$F_{triangle} = (\text{pressure}) \times (\text{area of triangle})$$

$$F_{triangle} = (5)(144)(1/2(2.5)(2.165)) = 1948.5 \text{ lbs}$$

This force will be supported by the three legs of the triangle. Therefore, the force exerted on a strut due to one triangle is:

$$F_{(t, \text{strut})} = F_{\text{triangle}} / 3$$

$$F_{(t, \text{strut})} = 1948.5 / 3 = 649.5 \text{ lbs}$$

Now since there are two triangles contributing to the distributed load on one strut, the total normal load on one strut is:

$$F_{\text{tot, normal}} = (2) \times (F_{t, \text{strut}})$$

$$F_{\text{tot, normal}} = (2) \times (649.5) = 1299 \text{ lbs}$$

The distributed force load can be determined from the length of the strut:

$$F_{\text{dist, strut}} = 1299 \text{ lbf} / 30.00 \text{ in}$$

$$F_{\text{dist, strut}} = 43.3 \text{ lb/in}$$

The maximum deflection would be:

$$Y_{\text{max}} = (5)(F_{\text{dist, strut}})(L^4) / (384)(E)(I)$$

$$\text{Where: } I = \pi(d^4 - d_i^4) / 64$$

$$I = \pi((2.0)^4 - (1.75)^4) / 64 = 0.325 \text{ in}^4$$

The length of the beam will be the strut length less the union overlap.

Since the union will extend approximately five inches from the theoretical center to the outside of the union, a total of ten inches can be subtracted from the strut length to determine the length between supports for the calculation of deflection.

$$L = 30 \text{ in} - 10 \text{ in}$$

$$L = 20 \text{ inches}$$

Therefore:

$$y_{\max} = (5)(43.3)(20)^4 / (384)(4 \times 10^6)(0.325)$$

$$y_{\max} = 0.069 \text{ inches}$$

This deflection would seem to be in a reasonable range and could be reduced easily by increasing wall thickness while keeping the two inch outside diameter.

Therefore a strut geometry that will withstand the pressure forces is:

$$d = 2.0 \text{ inches}$$

$$d_i = 1.75 \text{ inches}$$

$$t = \text{wall thickness} = 0.25 \text{ inches}$$

SUB-FRAME ANALYSIS

The sub-frame will transmit the loading that the dome is subjected to back to the orbital transfer vehicle. This will be accomplished (as stated in the design construction and assembly) using compression struts that connect directly to the underside of the union and then connect to the OTCV mounting plate.

Also, tension members will be used to tie into the center of the perimeter unions and then connect to the OTCV mounting plate (see exhibit 12).

Therefore, this analysis will begin with the compression members and then continue with the tension members. The same diameter tubing will be looked at in order to simplify manufacturing processes.

COMPRESSION MEMBERS

Since the same tubing will be used here, the maximum length that the mounting plate can stand off from the inside surface of the dome can be calculated.

The maximum total force that one compression member will need to withstand will be the pressure over the area of a hex unit cell.

$$F_{\max} = (\text{pressure}) \times (\text{area hex})$$

$$F_{\max} = (5)(144)(6 \times 1/2(250)(2.165))$$

$$F_{\max} = 11,691 \text{ lbf}$$

The same material will be used for this compressive member; therefore, the critical load can be calculated using a lower factor of safety of (2) since there are no bending forces present.

$$P_{cr} = nF_{max} = 2(11,691) = 23,382 \text{ lbf}$$

Now the compressive column equation can be solved for the compressive member length:

$$L = (C\pi^3 E(d^4 - d_i^4) / 64P_{cr})^{1/2}$$

$$L = ((1.2)\pi^3(4 \times 10^6)((2.0)^4 - (1.75)^4) / 64(23,382))^{1/2}$$

$$L = 25.67 \text{ inches}$$

This length will be the mounting plate stand-off distance from the inside center of the dome.

TENSILE MEMBERS

Again, the same tubing will be utilized here. The force per tube will be calculated by determining the total force on the dome outside the compression members divided by the number of perimeter hex cells.

First, the compressive members will support an approximate 20 ft circular area in the center of the dome; therefore, the total area that will distribute forces to the tension members is:

$$A_{tension} \cong A_{total} - A_{comp}$$

$$A_{tension} \cong (\sqrt{2}/4)\pi(40)^2 - (\sqrt{2}/15)\pi(40)^2$$

$$A_{tension} \cong 1777 \text{ ft}^2 - 474 \text{ ft}^2 = 1303 \text{ ft}^2$$

Now assuming that the pressure everywhere over this area is at the same maximum pressure of five psi. Now the total force can be calculated:

$$F_{\text{tot,tension}} = (5)(144)(1303)$$

$$F_{\text{tot,tension}} = 938,160 \text{ lbf}$$

To calculate the force in each tension member, divide by the number of members, which is the number of hex units on the perimeter of the dome (8 rows).

$$\text{Number of Hex units in 8}^{\text{th}} \text{ row} = 42$$

Therefore:

$$F_{\text{tension,mem}} = 938,160/42$$

$$F_{\text{tension,mem}} = 22337 \text{ lbf}$$

Now the cross sectional area of the tube will be computed.

$$A_{\text{CS}} = \pi d^2/4 - \pi d_i^2/4$$

$$A_{\text{CS}} = \pi(2.0)^2/4 - \pi(1.75)^2/4 = 0.736$$

$$A_{\text{CS}} = 0.736$$

Now the tensile stress in the tensile member can be calculated.

$$\sigma_t = F/A = 22,337 / 0.736$$

$$\sigma_t = 30,336 \text{ psi}$$

Since the tensile strength of the aluminoborosilicate is 250,000 psi, the safety factor in the tensile members can be calculated.

$$n = \sigma_t / \sigma$$

$$n = 250,000 / 30,336$$

$$n = 8.24$$

STRUCTURAL ANALYSIS

CONCLUSION

The results from the structural analysis show that a strut that is 2.5 ft long and tubular in geometry with an outside diameter of 2.00 inches and an inside diameter of 1.75 inches will withstand the loading that it is subjected to during the aerobraking process.

Also, from the cover analysis, a standard weave of the ceramic fiber will withstand the forces due to the drag pressure exerted against it.

The sub-frame assembly analysis showed that the same diameter tubing that is used for the struts can successfully be used for the subframe and withstand all forces encountered in aerobraking.

At this point, it will be taken that the union as a solid hexagonal shape can easily withstand the compressive forces that the struts exert. This will allow simple machining processes to manufacture the unions. However, further analysis may be done to minimize the material volume and weight of the unions if this becomes a problem. Complicated processing would be necessary at this point, and would not be practical if high demand was not apparent.

HAZARDS

This section will denote certain design parameters that were set relating to safe operation of this aerobrake.

For safe operation of this design, it must be noted that the aerobrake was not designed for use with manned vehicles. One of the design assumptions was the ability to make multiple passes through the atmosphere to improve the efficiency of the system. As this would involve multiple passes through the Van Allen radiation belts, it was deemed unwise to consider a manning such a vehicle.

The inspection and testing, including radiation testing, of all functional entities must be maintained on a regular basis to insure safe operation throughout the life of the aerobrake.

LIFETIME

The lifetime of the aerobrake will depend largely on the thermal stressing and ablation of the materials used in the design. If the structure did not encounter these forces, its lifetime would be extremely long, under the design loading. Since thermal effects and ablation are present the best method for determining the life of the system is to inspect and test the structure after every use. A testing fixture can be used to apply simulated loading at key points about the structure. Also, if ablation appears extreme, the strength of the structural members should be tested.

The cover of the aerobrake has been designed to be easily removed and replaced. This is because the cover system will be experiencing loading and large thermal gradients that are anticipated to be orders of magnitude greater than the stresses applied to the structural members. Therefore, the structure can be used many times, with a new cover as necessary.

Actual testing will be necessary to determine the lifetime of the components of the aerobrake. Regular inspection intervals must be maintained during operation in order to obtain safe consistent aerobraking.

ALTERNATE DESIGNS

Several alternate designs were discussed in the process of arriving at the final design. Some of the ones that may have individual merit are as follows:

One such design would be to keep the same basic structure, but decrease the thickness of the front cover. To keep the same level of thermal mass the back of the shield could be insulated with one of the inorganic refractory foams that have been recently developed.

This same type of foam could be used to make a self supporting structure, by filling a balloon made from ceramic cloth. With proper support this would work and would require fewer manufacturing steps.

Another alternative would be to use the same type of support structure as the one specified in this report, but not cover it. It might be necessary to make the triangles smaller; however, if the structure provided enough drag and could survive, it would become an aerobrake in itself.

The last alternative would be to use some of the additional techniques discussed in the materials section of this paper to form glass composite sandwich panels. These panels would be self-supporting and would require little supporting structure. They could also be used in designs that would provide lift as well as drag.

CONCLUSION

Overall, the project was succesful. Almost all of the criteria given in the problem statement were met. This appears to be a feasible project. The only real area of neglect is with the thermal analysis. Since this is an extremely complicated problem, it was not possible to handle it in the time available. The problem may, in fact, be to complicated for an undergraduate project.

This design should provide at least a starting point from which to pursue this problem further. The criteria of reusability and lunar manufacture are good starting points and the material in this paper should provide assistance to anyone interested in this problem.

SUGGESTIONS

1. The project of designing an aerobrake from raw materials to finished product is too large for a group of four people to adequately cover in one quarter. The project should be broken down into at least three separate projects to do justice to the topic.
2. Other groups which work on this project should consider shapes with some lift.
3. A better model for re-entry should be established to evaluate designs.
4. The alternate materials that were discussed in the text should be further investigated.

APPENDIX

KAO-TEX 2200 CERAMIC FIBER
Thermal Conductivity

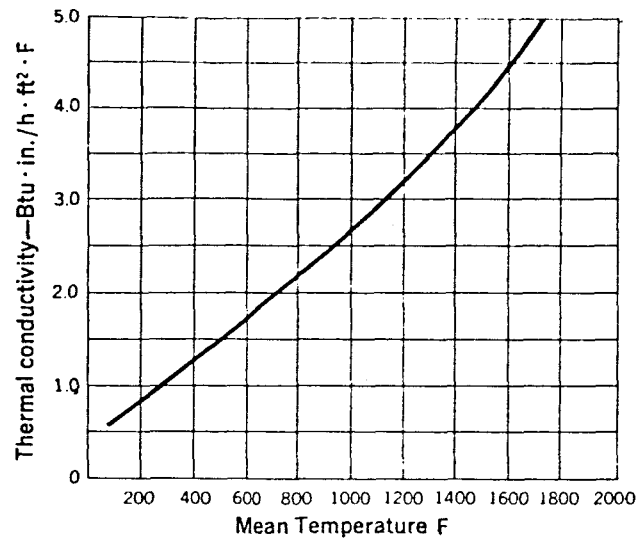


Figure 1: Thermal Conductivity versus Temperature

Physical properties

Color.....	white
Fiber diameter, microns (avg.).....	11
Fiber length, inches.....	continuous
Specific gravity (ASTM C 135).....	2.7
Specific heat Btu/lb/F @ 1800 F mean.....	0.32
Fiber tensile strength, psi.....	250×10^3
Fiber tensile modulus, psi.....	22×10^6
Use limit, °F (max).....	2600
Melting point, °F.....	3200

Figure 2: Summary of Physical Properties of the
aluminoborosilicate fiber textile cloth

	<i>Name</i>	<i>Formula</i>
Major (> 10%)	Pyroxene	$(\text{Ca,Fe,Mg})_2\text{Si}_2\text{O}_6$
	Plagioclase	$(\text{Ca,Na})(\text{Al,Si})_4\text{O}_8$
	Ilmenite	FeTiO_3
Minor (1-10%)	Olivine	$(\text{Mg,Fe})_2\text{SiO}_4$
	Cristobalite	SiO_2
	Tridymite	SiO_2
	Pyroxferroite	$\text{CaFe}_9(\text{SiO}_3)_7$
Accessory (< 1%)	Copper	Cu
	Iron	Fe
	Nickel-iron	(Fe,Ni)
	Cohenite	Fe_3C
	Schreibersite	$(\text{Fe,Ni})_3\text{P}$
	Troilite	FeS
	Potash feldspar	KAlSi_3O_8
	Quartz	SiO_2
	Armcolite	$(\text{Fe,Mg})\text{Ti}_2\text{O}_5$
	Ulvöspinel	Fe_2TiO_4
	Chromite	FeCr_2O_4
	Spinel	MgAl_2O_4
	Perovskite	CaTiO_3
	Rutile	TiO_2
	Baddeleyite	ZrO_2
	Zircon	ZrSiO_4
	Apatite	$\text{Ca}_5(\text{PO}_4)_3(\text{F,Cl})$
	Whitlockite	$\text{Ca}_3(\text{PO}_4)_2$

Figure 3: Summary of materials found in lunar rocks obtained from Apollo XI crew

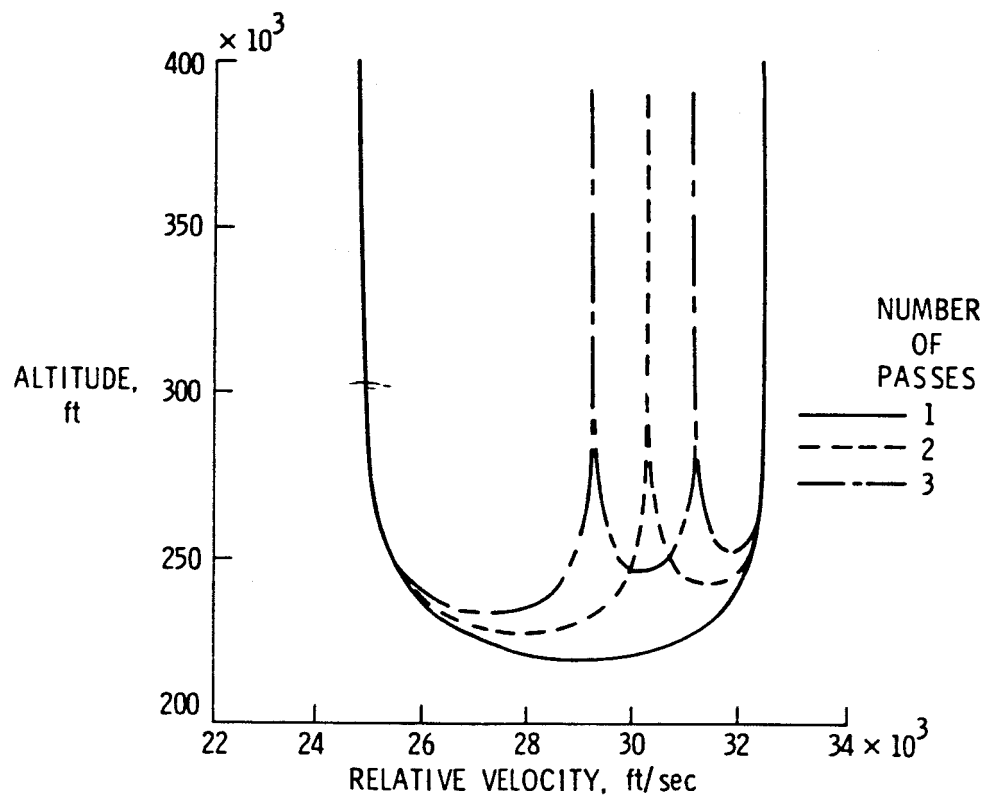


Figure 4: Altitude history during the atmospheric passes.

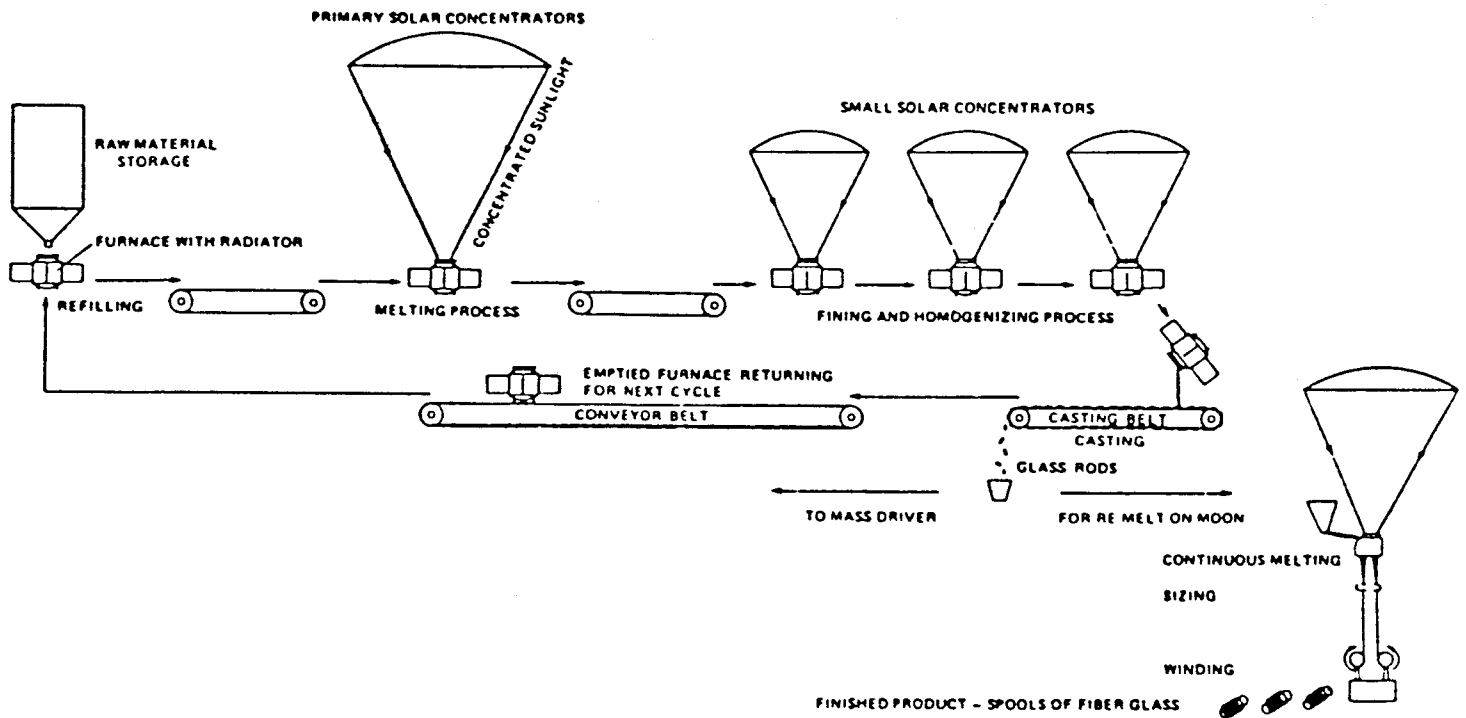


Exhibit 1: The lunar fiberglass manufacturing operation

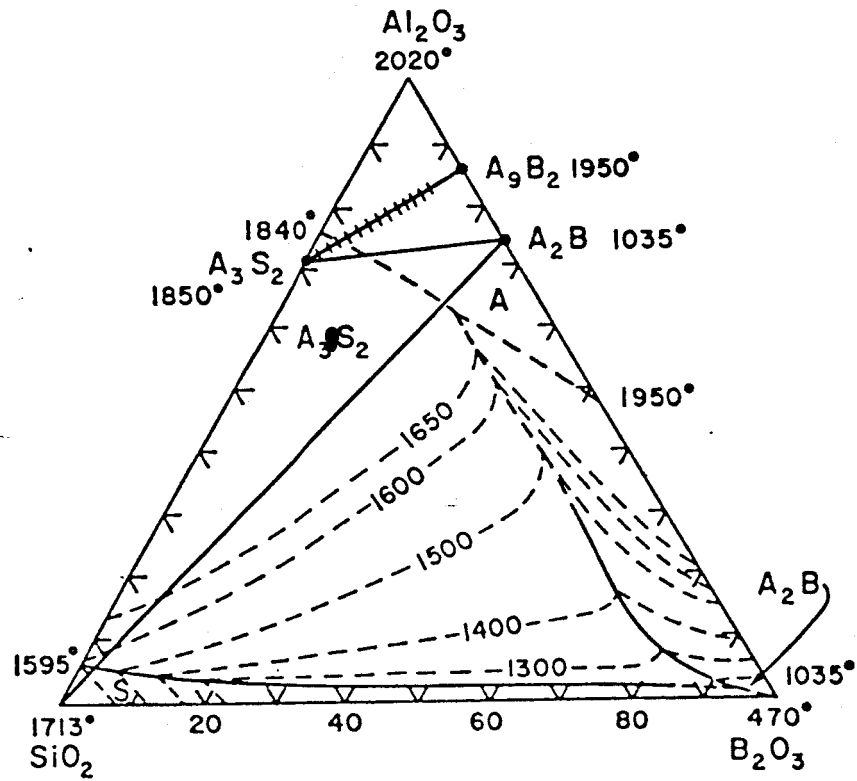


Exhibit 2: The ternary phase diagram for the system: Al₂O₃, SiO₂, and B₂O₃

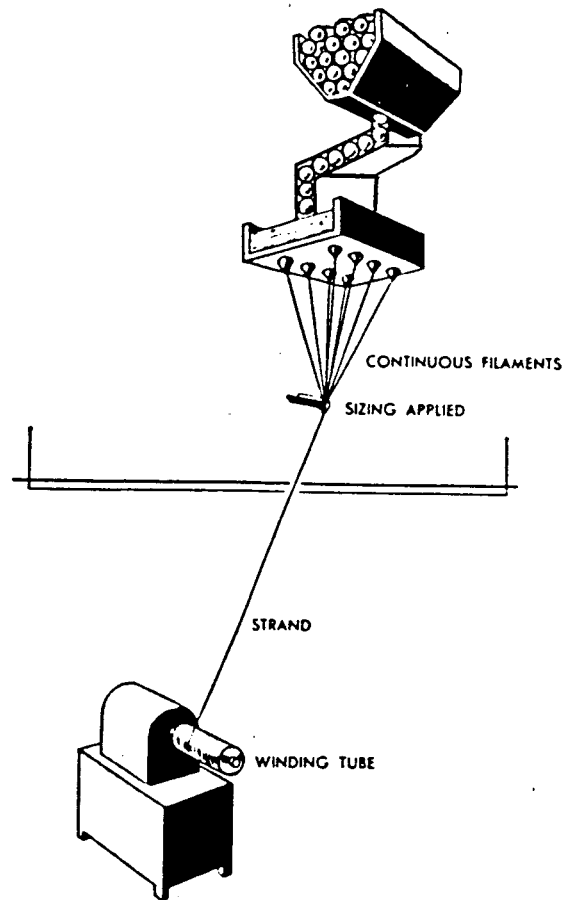


Exhibit 3: The manufacture of glass fibers

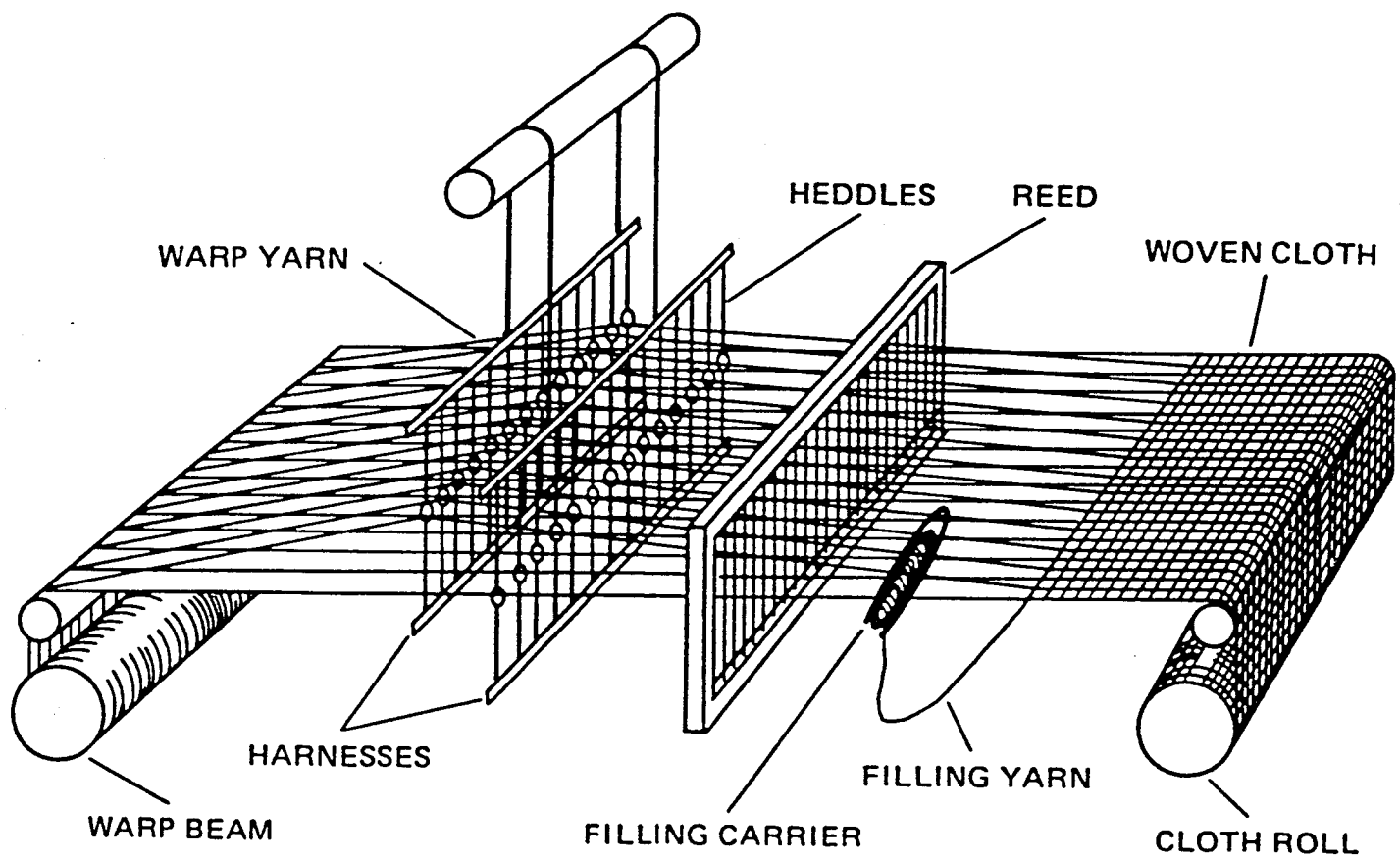


Exhibit 4: Weaving process for ceramic fiber textile

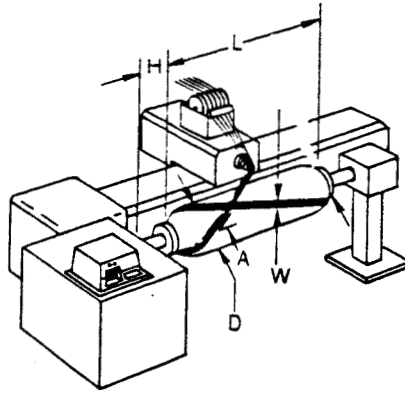


Exhibit 5: Apparatus for forming composite rods

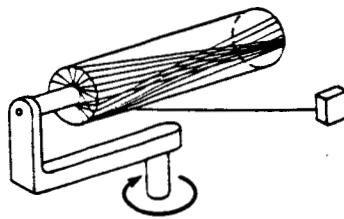


Exhibit 6: Helical winding pattern for composite rods

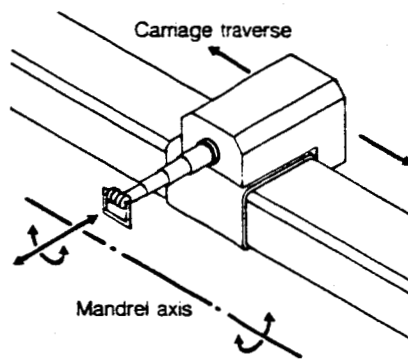
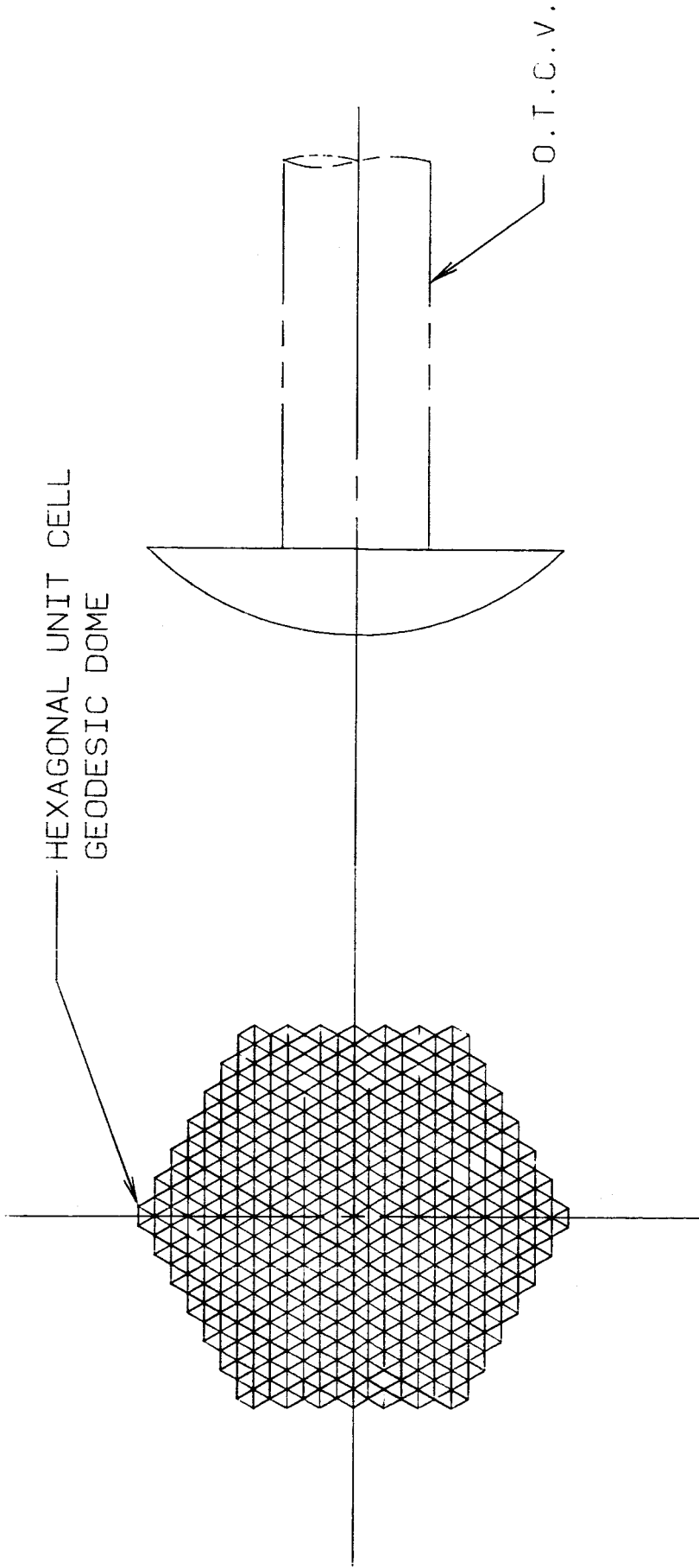
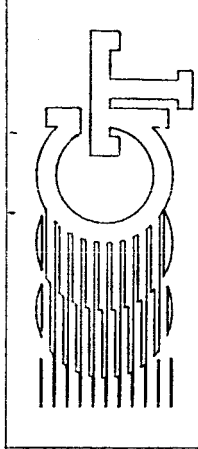


Exhibit 7: View of winding movements used to form rods

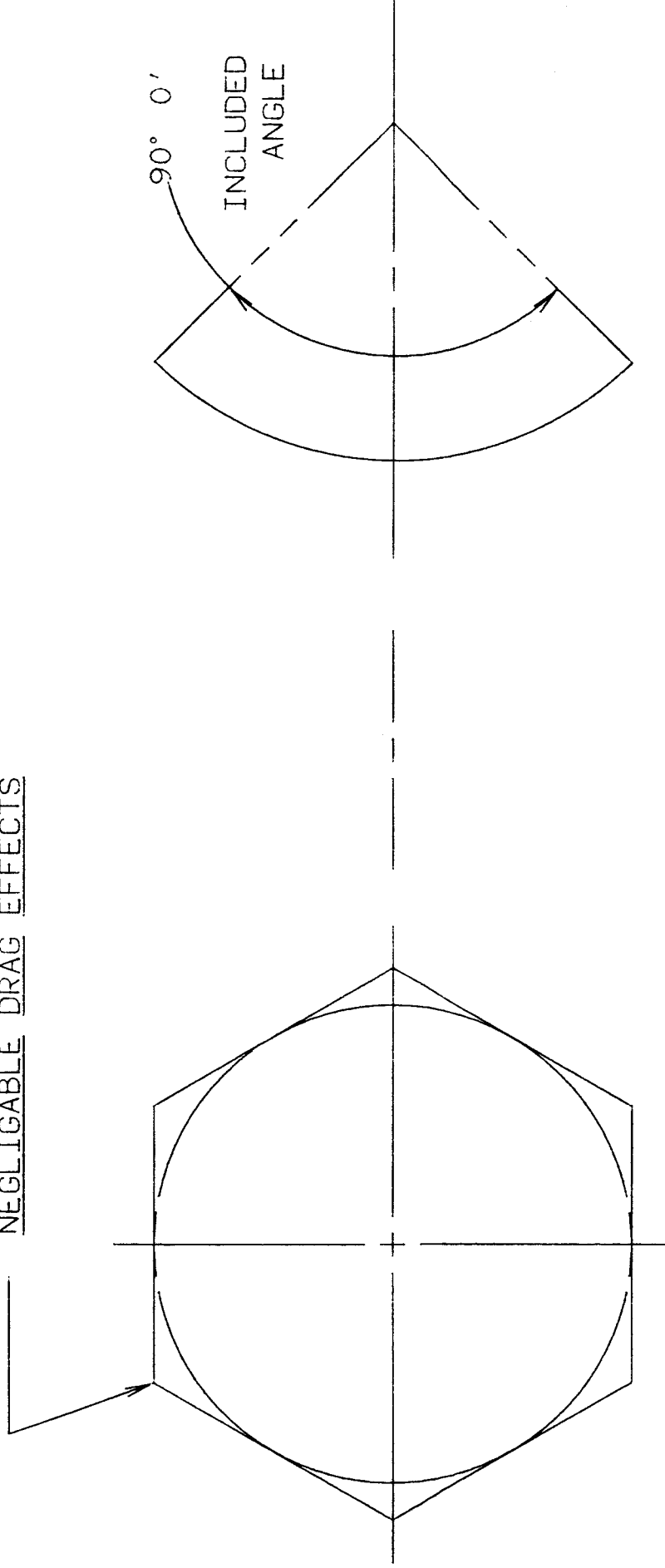
LAST UPDATED:	



NASA / UNIVERSITY
ADVANCED DESIGN CONCEPTS
DEPT. MECHANICAL ENGINEERING
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DESIGN: SCA DATE 2/86
CHECK: SCA DATE 2/86
DRWG NO. EXHIBIT 1

TOLERANCE UNLESS OTHERWISE NOTED:
IN: MM:
MATL:
SCALE:

NEGLIGABLE DRAG EFFECTS



NASA / UNIVERSITY

ADVANCED DESIGN CONCEPTS

TITLE: AEROBRAKE

DESIGN: SCA DATE 2/86

CHECK: SCA DATE 2/86

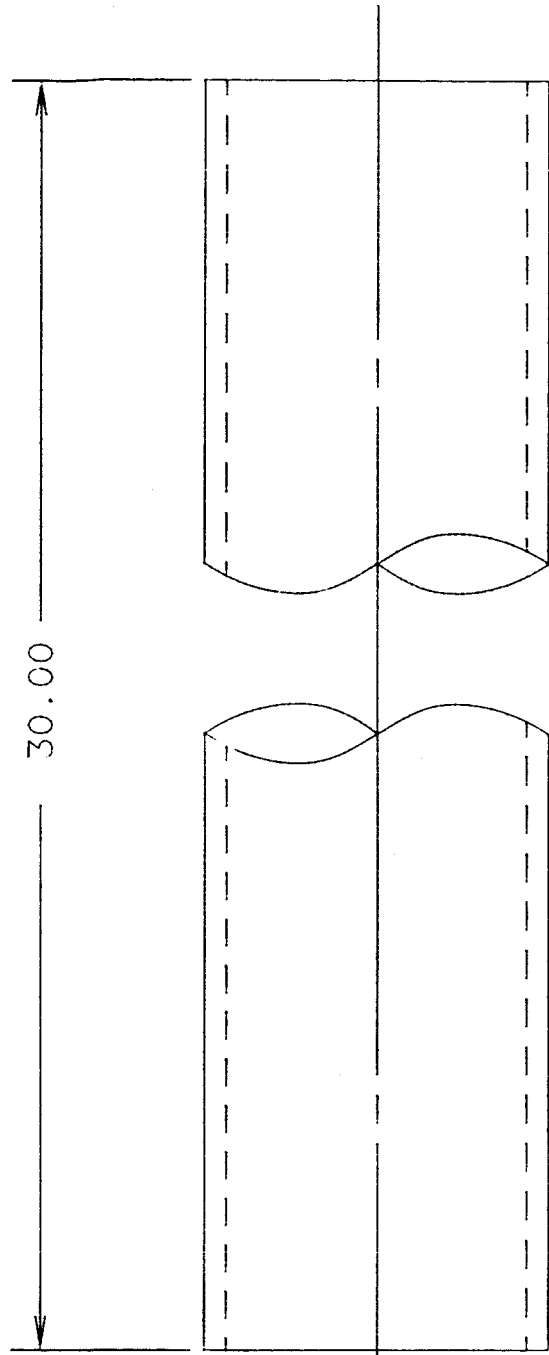
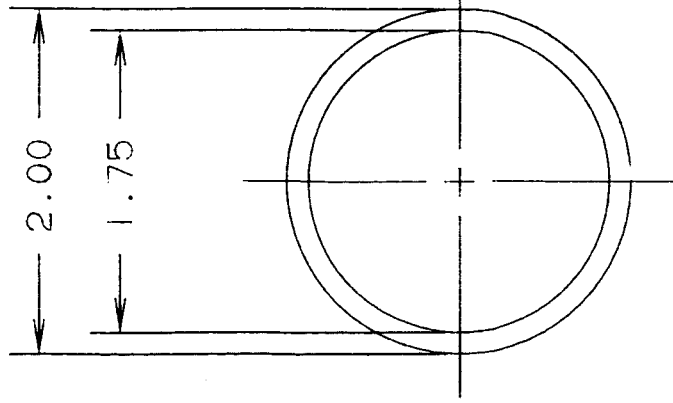
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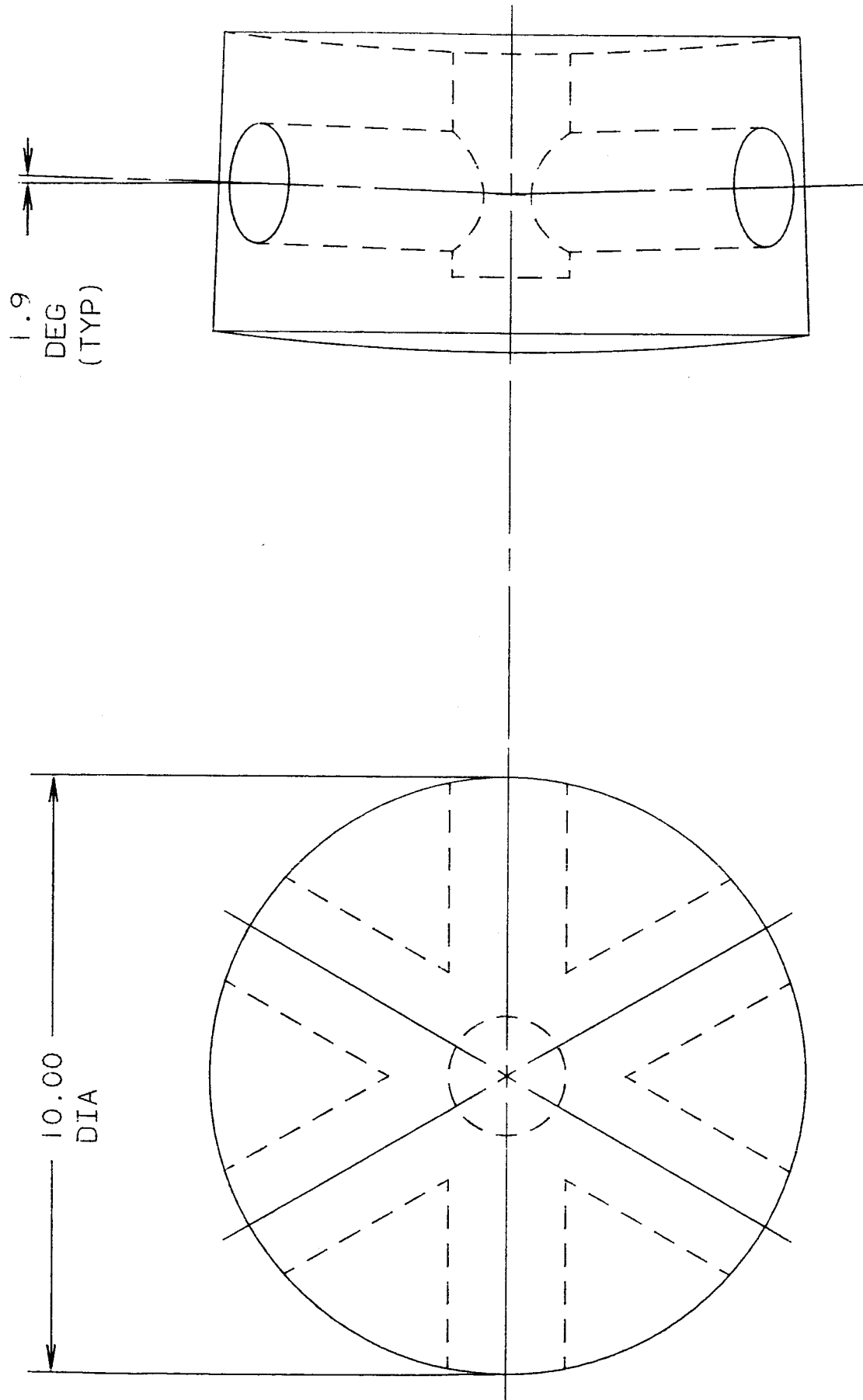
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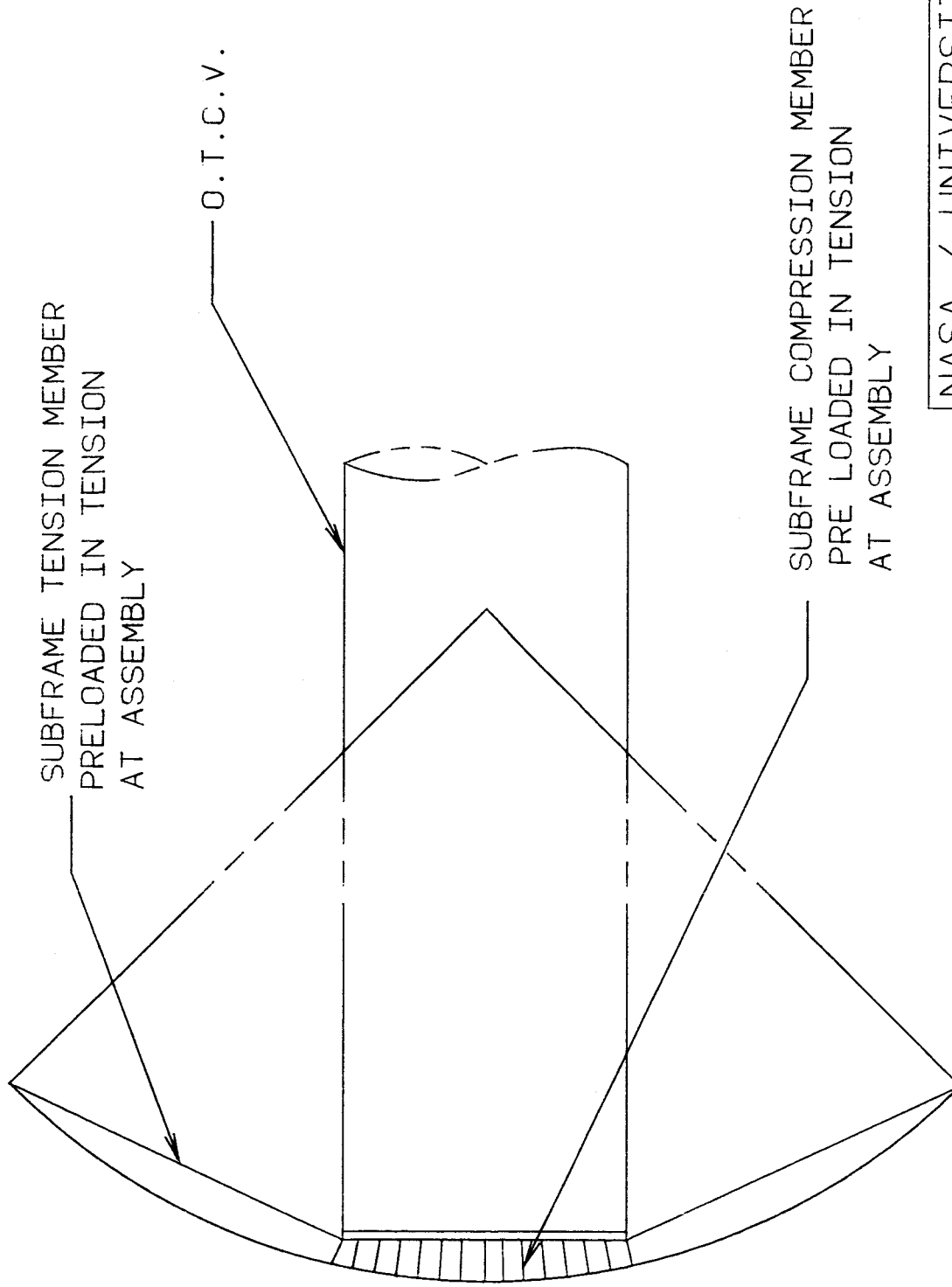
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MATL:	
SCALE:	

NASA / UNIVERSITY ADVANCED DESIGN CONCEPTS			
TITLE: STRUT ASSEMBLY			
FOR AEROBRAKE			
DESIGN:	SCA	DATE	2/86
CHECK:	SCA	DATE	2/86
DRWG NO.	EXHIBIT 3A		



NASA / UNIVERSITY ADVANCED DESIGN CONCEPTS	
TITLE:	UNION
AEROBRAKE ASSEMBLY	
DESIGN:	SCA DATE 2/86
CHECK:	SCA DATE 2/86
DRWG NO.	EXHIBIT 3B

TOLERANCE UNLESS OTHERWISE NOTED:	
IN:	MM:
MATL:	
SCALE:	



CONCEPT DWG ONLY

TOLERANCE UNLESS
OTHERWISE NOTED:

IN: MM:

MATL:

SCALE:

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ADVANCED DESIGN CONCEPTS

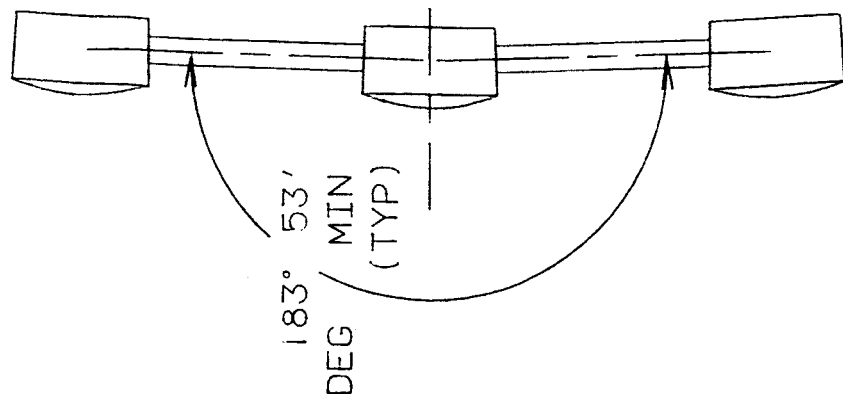
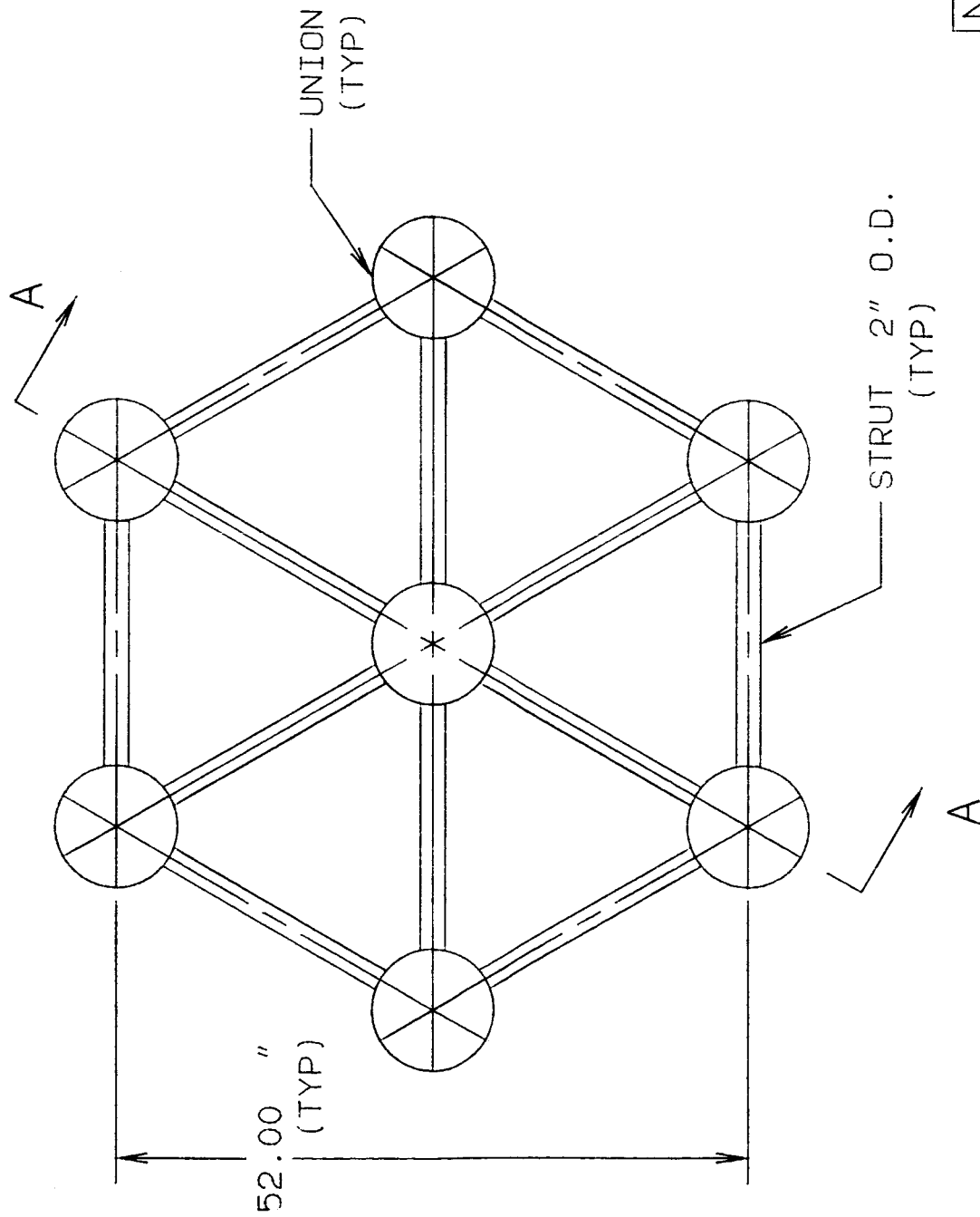
TITLE: AEROBRAKE

SUBFRAME

DESIGN: SCA DATE 2/86

CHECK: SCA DATE 2/86

DRWG NO. EXHIBIT 4



NASA / UNIVERSITY

ADVANCED DESIGN CONCEPTS

TITLE: AEROBRAKE

HEXAGONAL UNIT CELL

DESIGN: SCA DATE 2/86

CHECK: SCA DATE 2/86

DRWG NO. EXHIBIT 5

TOLERANCE UNLESS
OTHERWISE NOTED.

IN. MM:

MATL:

SCALE:

```

1      PROGRAM GEOBRK ( INPUT, OUTPUT )
2      C
3      C      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
4      C
5      C      THIS PROGRAM CALCULATES GOEMETRIC RELATIONS OF
6      C      THE AEROBRAKE USING THE GEODESIC DOME
7      C      CONSTRUCTION.
8      C
9      C      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
10     C
11     C      VARIABLE DECLARATION
12     C
13     REAL    FDB, LEN, YMAX, HOLD2, IDB, ID , HOLD5
14     REAL    ALLOWAR, FIBNUM, FIBCHO, FIBDEN, PCRIT2
15     REAL    RADIUS, STRUT, HEX, THETA, TOTFOR, PMAX
16     REAL    AREA, ALLOWST, SIGMAT, HOLD, HOLD1, OD
17     REAL    IDC, PCRIT, EMOD, HOLD3
18     INTEGER ROWNUM, HEXNUM, UNION, J, LESNUM, INSSUP
19     INTEGER OUTSUP, TOTSUP, K
20     REAL    VOLSTR, MSTRUT, DENSTR
21     C
22     C      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
23     C
24     C      DATA PROMPT
25     C
26     PRINT*, 'ENTER EQUILATERAL LEG SIZE IN FT. (REAL)'
27     READ*, STRUT
28     PRINT*, 'ENTER SPHERICAL RADIUS IN FT. (REAL)'
29     READ*, RADIUS
30     PRINT*, 'ENTER NUMBER OF ROWS (INTEGER)'
31     READ*, ROWNUM
32     PRINT*, 'ENTER MATERIAL TENSILE STRENGTH-PSI (REAL)'
33     READ*, SIGMAT
34     PRINT*, 'ENTER MAX EXTERNAL PRESSURE-PSI (REAL)'
35     READ*, PMAX
36     PRINT*, 'ENTER STRUT O.D.-INCHES (REAL)'
37     READ*, OD
38     PRINT*, 'ENTER STRUT MATERIAL MODULUS-PSI (REAL)'
39     READ*, EMOD
40     PRINT*, 'ENTER MAX ALLOWABLE STRUT DEFLECTION'
41     PRINT*, 'RANGE -0.020-0.125 INCH (REAL)'
42     READ*, YMAX
43     PRINT*, 'ENTER STRUT DENSITY, KG/M**3 (REAL)'
44     READ*, DENSTR
45     C
46     C      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
47     C
48     C      CALCULATE UNIT HEXIGON SIZE
49     C
50     HEX = 2.0 * SQRT (STRUT**2 - (STRUT/2.0)**2)
51     C
52     C      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
53     C
54     C      CALCULATE UNION ANGLE
55     C

```

```

56      HOLD5 = STRUT/(2.0 * RADIUS)
57      THETA = 90.0 - 57.296 * ACOS ( HOLD5 )
58      C
59      C
60      C
61      C          CALCULATE NUMBER OF UNIT HEX CELLS
62      C          CALCULATE NUMBER OF UNIONS
63      C
64      HEXNUM = 0
65      UNION = 6
66      LESNUM = ROWNUM - 1
67      DO 10 J=1, LESNUM
68          HEXNUM = HEXNUM + J * 6
69          UNION = UNION + (2 * J + 1) * 6
70      10 CONTINUE
71      HEXNUM = HEXNUM + 1
72      UNION = UNION + HEXNUM
73      C
74      C
75      C
76      C          COMPUTE NUMBER OF STRUTS
77      C
78      INSSUP = 42
79      OUTSUP = 30
80      DO 20 K=2, LESNUM
81          INSSUP = INSSUP + 36 * K
82          OUTSUP = OUTSUP + 18 + 2 * (6 * K - 6) + K * 6
83      20 CONTINUE
84      TOTSUP = INSSUP + OUTSUP
85      C
86      C
87      C
88      C          NOW DETERMINE THE FIBER (FIBERS/FT**2) DENSITY
89      C          THAT MUST BE USED TO SPAN THE EQUILATERAL
90      C          TRIANGLE WITH THE EXTERIOR CLOTH COVER SAFETY
91      C          FACTOR 4.
92      C
93      AREA = STRUT * HEX / 4.0
94      TOTFOR = PMAX * AREA
95      ALLOWST = SIGMAT / 4.0
96      ALLOWAR = TOTFOR / ALLOWST
97      C      XXX USE CHORD DIAMETER OF 0.048 XXX
98      C      XXX USE GIVEN FIBER DIAMETER OF 11 MICRONS XXX
99      C
100     FIBNUM = ALLOWAR / 1.473E-7
101     FIBCHO = 0.00181 / 1.473E-7
102     FIBDEN = FIBNUM / FIBCHO / AREA
103     C
104     C
105     C
106     C          NOW CALCULATE THE STRUT DIAMETER BY COMPRESSIVE
107     C          FORCES.
108     C
109     PCRIT = 4.0 * TOTFOR
110     HOLD = 64.0 * PCRIT * (STRUT * 12.0) **2
111     HOLD1 = 1.2 * 31.0063 * EMOD
112     IDC = (OD**4 - HOLD/HOLD1) ** 0.25

```

```

113      C
114      C      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
115      C
116      C      NOW COMPUTE DIAMETER BY BENDING FORCES
117      C
118      FDB = (0.667 * TOTFOR) / (STRUT * 12.0)
119      LEN = (STRUT * 12.0) - 10.0
120      HOLD2 = FDB * (LEN **4) / EMOD * YMAX
121      IDB = (OD - 0.26526 * HOLD2) ** 0.25
122      C
123      C      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
124      C
125      C      NOW COMPUTE MOUNTING PLATE STANDOFF DISTANCE
126      C
127      PCRIT2 = 2.0 * 6.0 * TOTFOR
128      HOLD3 = 0.5814 * EMOD / PCRIT2
129      IF ( IDB .LT. IDC ) THEN
1 130          LCOMP = SQRT ( HOLD3 * (OD**4 - IDB**4))
1 131          ID = IDB
1 132      ELSE
1 133          LCOMP = SQRT ( HOLD3 * (OD**4 - IDC**4))
1 134          ID = IDC
1 135      ENDIF
1 136      C
1 137      C      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1 138      C
1 139      C      CALCULATE AEROBRAKE TOTAL WEIGHT (APPROX.)
1 140      C
141      VOLSTR=12.0*STRUT*(1.571*((OD/2.0)**2-(ID/2.0)**2))
142      MSTRUT = VOLSTR * DENSTR * 1.6387E-5
143      C
144      C      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
145      C
146      C      PRINT STATEMENTS
147      C
148      PRINT*, ' '
149      PRINT*, ' '
150      PRINT*, 'XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX'
151      PRINT*, ' '
152      PRINT*, 'THE STRUT LENGTH IS: ', STRUT
153      PRINT*, 'THE NUMBER OF STRUTS IS: ', TOTSUP
154      PRINT*, 'THE MASS OF ONE STRUT IS: ', MSTRUT
155      PRINT*, ' '
156      PRINT*, 'THE NUMBER OF UNIONS IS: ', UNION
157      PRINT*, 'THE NUMBER OF HEX CELLS IS: ', HEXNUM
158      PRINT*, 'THE UNION ANGLE IS: ', THETA
159      PRINT*, ' '
160      PRINT*, 'THE STRUT O.D. IS: ', OD
161      PRINT*, 'THE STRUT I.D. IS: ', ID
162      PRINT*, 'THE MOUNTING PLATE STAND-OFF '
163      PRINT*, 'DISTANCE IS: ', LCOMP
164      PRINT*, ' '
165      PRINT*, 'XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX'
166      PRINT*, ' '
167      C
168      STOP
169      END

```

```

#include stdio.h
#include event.h
#include quickdraw.h
#include window.h

/*****
/* Name : ORBIT
Programmer : Jeff Shumate
Purpose : This program is used to calculate the position
velocity and acceleration of a ship that is in
an orbit around the earth. It takes into account
the influence of the moon, as well as the influence
of the atmosphere if the ship is within 300 km of
the earth's surface.
*****/

EventRecord event;
float FX, FY; /* Force on ship in Newtons */
float Fex,Fey,Fmx,Fmy;
float Fvx,Fvy; /*Force components */
float ShipX, ShipY; /* Ships position in meters */
float ShipVX, ShipVY; /* Ships velocity in m/s */
float ShipAX, ShipAY; /* ships accel. in m/secSqr */
float MoonX1, MoonY1;
float MassE, MassM;
float MassS; /* masses in kilograms */
float ThetaM, Dtheta; /* theta of moon, d theta */
float MoonR; /*moons orbital radius in meters */
float G; /* Gravitational const. */
float ScaleFac; /* scale factor */
float Dist1,Dist2,Dist3; /*Dist. at which DT changes*/
float Dist4,Dist5,Dist6;
float DeSqrD, DmSqrD,D2; /*dist. sqrD between ship */
/* and earth or moon */
float multFact; /*common factor G*MassShip */
float F1fact, F2fact,Ufact; /*factor common to force 1 and 2 */
float DeltaT,DeltaTsqr,T2; /* delta time, delta time sq */
float Height, Rho,TotalV; /*Height above E. Density,Velocity*/
float H1[7],h1[7],a[7]; /* values used in calculating Rho */
float Rho1[7],H,Hexp; /* ditto */
float Cd, SurfA; /* Drag Coef. and Surface Area */
float Mradius,Eradius; /* Earth and Moon's radius in m. */
float sin(); /* type declaration of external funct. */
float cos();
float sqrt();
float pow();
static float MoonX[657];
static float MoonY[657]; /*Moons position in meters*/
int ElapsedT,T1; /* total elapsed time. */
int screenx, screeny; /* position on screen */
int scrnwidth, scrnheight; /* screen hight and width */
int i;
char response;

main() {

/*****/

```

```

/* initialize all of the necessary program variables */
/*****/

scrnwidth = 546;
scrnheight = 364;
MassE = 5.98E24; /* mass of earth in kilograms */
MassM = 7.35E22; /* mass of moon in kilograms 7.35E22 */
MassS = 3.178571E4; /* mass of the ship in kilograms*/
Mradius = 1.738E6;
Eradius = 6.378E6;
G = 6.672E-11; /* gravitational constant */
ScaleFac = 2.0E8; /*factor to scale the values by */
SurfA = 116.745; /* meters squared */
Cd = 2.43;
ThetaM = 0.0; /* moons initial theta value */
Dtheta = 6.283185307/2360591.424; /* 2pi/number of sec in lunar month*/
MoonR = 1.922015E8; /*moons radius in polar coord */
multFact = G * MassS; /*common term in force calculations*/
Dist1 = 1.0E16;
Dist2 = 5.0E15;
Dist3 = 1.0E15;
Dist4 = 5.0E14;
Dist5 = 1.0E14;
Dist6 = 4.46E13; /* Dist. to outer atmosphere */

/* fill an array with values for the moons position each hour */
for (ElapsedT=1; ElapsedT<657; ElapsedT++) {
    MoonX[ElapsedT] = MoonR * cos(ThetaM);
    MoonY[ElapsedT] = MoonR * sin(ThetaM);
    ThetaM = ThetaM + Dtheta * 3600;
}
ThetaM = 0;

/* initialize the values necessary for the density approximation */
Hi[1] = 6.6597;
hi[1] = 67;
a[1] = -0.1296385;
Rhoi[1] = 1.4974E-4;
Hi[2] = 4.979;
hi[2] = 85;
a[2] = 0.1545455;
Rhoi[2] = 7.26E-6;
Hi[3] = 5.905;
hi[3] = 99;
a[3] = 0.1189286;
Rhoi[3] = 4.504E-7;
Hi[4] = 8.731;
hi[4] = 110;
a[4] = 0.5925240;
Rhoi[4] = 5.930E-8;
Hi[5] = 42.62;
hi[5] = 170;
a[5] = .3054545;
Rhoi[5] = 7.932E-10;
Hi[6] = 46.51;
hi[6] = 190;
a[6] = 0.1596875;

```

```

Rhoi[6] = 4.680E-10;
Hi[7] = 54.78;
hi[7] = 254;
a[7] = 0.1190323;
Rhoi[7] = 1.149E-10;

top:
ShipX      = 1.82820E8;          /*dist. at which orbital speed around */
                                   /* moon =300m/s y rel. to earth.    */
ShipY      = 0.0;

/* get the values for the ships velocity */
printf("Input ship VX and VY, pictorial view y,n,e\n");
scanf("%f %f %c",&ShipUX, &ShipUY,&response);

if (response == 'e') return();
if (response == 'y' ) {
screenx = ShipX/ScaleFac*(scrnwidth/2) + (scrnwidth/2);
screeny = -ShipY/ScaleFac*(scrnhight/2) + (scrnhight/2);
InitWindows();
MoveTo(0,(scrnhight/2));
LineTo(scrnwidth,(scrnhight/2));
MoveTo((scrnwidth/2),0);
LineTo((scrnwidth/2),(scrnhight));
MoveTo(screenx,screeny);
}

DeSqrd = ShipX * ShipX;
DmSqrd = (MoonX[1]-ShipX)*(MoonX[1]-ShipX);
ElapsedT = 0;

/* begin a loop that will repeat every hour of simulated time */
while ( ElapsedT < 72)
{
/* if the mouse button has been clicked start over */
if (GetNextEvent(&mDownMask,&event)) goto top;
/*****/

ThetaM = ThetaM + (Dtheta * 3600 * ElapsedT);
T1 = 0;

/* begin a loop that will repeat every minute */
while ( T1 < 60)
{
/* using the distance values decide on a time increment */
D2 = (DeSqrd < DmSqrd) ? DeSqrd : (DmSqrd*25);
if (D2 > Dist1)
DeltaT = 60;
else if (D2 > Dist2)
DeltaT = 12;
else if (D2 > Dist3)
DeltaT = 6;
else if (D2 > Dist4)
DeltaT = 3;
else if (D2 > Dist5)
DeltaT = 2;

```



```

else if (D2 > Dist6)
DeltaT = 1;
else DeltaT=0.1;
DeltaTsqr = DeltaT * DeltaT;

ThetaM = ThetaM + (Dtheta * 60 * T1);
T2 = 0;

/* begin a loop that will repeat every second */
while (T2 <= 60)
{
    /* calculate forces */

    /* first the force from the earth */
    DeSqr = ((ShipX * ShipX) + (ShipY * ShipY));
    F1fact = MassE/(DeSqr * sqrt(DeSqr));
    Fex = multFact * (-F1fact*ShipX);
    Fey = multFact * (-F1fact*ShipY);

    /* then the force from the moon */
    if (DeSqr > 1E16) {
        MoonX1 = MoonX(ElapsedT) + MoonR * cos(ThetaM);
        MoonY1 = MoonY(ElapsedT) + MoonR * sin(ThetaM);
        ThetaM = ThetaM + Dtheta * T2;
        DmSqr=((MoonX(ElapsedT)-ShipX)*(MoonX(ElapsedT)-ShipX))
            +((MoonY(ElapsedT)-ShipY)*(MoonY(ElapsedT)-ShipY));
        F2fact = MassM/(DmSqr*sqrt(DmSqr));
        Fmx = multFact * F2fact*(MoonX(ElapsedT)-ShipX);
        Fmy = multFact * F2fact*(MoonY(ElapsedT)-ShipY);
    }

    /* then the force from the atmosphere */
    if (DeSqr < 4.46E13) {
        Height = (sqrt(DeSqr) - 6.378E6)/1000;
        if (Height > 207) i = 7;
        else if (Height > 175) i = 6;
        else if (Height > 164) i = 5;
        else if (Height > 107) i = 4;
        else if (Height > 91) i = 3;
        else if (Height > 80) i = 2;
        else i = 1;
        Hexp = (1 + a[i])/a[i];
        H = Hi[i] + (a[i]*(Height - hi[i]));
        Rho = Rho[i] * pow((Hi[i]/H),Hexp);
        Ufact = Cd*Rho*SurfA/2;
        Fvx = (ShipUX<0) ? (Ufact*ShipUX*ShipUX) :
            (-Ufact*ShipUX*ShipUX);
        Fvy = (ShipUY<0) ? (Ufact*ShipUY*ShipUY) :
            (-Ufact*ShipUY*ShipUY);
        if (response != 'y') printf("Rho= %g U= %g Height= %g\n",Rho,TotalU,Height);
    }
    else {Fvx=0; Fvy=0;}
    FX= Fex + Fmx + Fvx;
    FY= Fey + Fmy + Fvy;
    /* end fo calculate forces */

    ShipAX = FX/MassS;

```

```

        ShipAY = FY/MassS;
        ShipUX = ShipUX + ShipAX * DeltaT;
        ShipUY = ShipUY + ShipAY * DeltaT;
        ShipX = ShipX + ShipUX * DeltaT + ShipAX * DeltaTsqr;
        ShipY = ShipY + ShipUY * DeltaT + ShipAY * DeltaTsqr;
        TotalV = sqrt((ShipUX*ShipUX)+(ShipUY*ShipUY));
        T2 = T2 + DeltaT;
    }
    T1++;
    if (response == 'y') {
        screenx = ShipX/ScaleFac*(scrnwidth/2) + (scrnwidth/2);
        screeny = -ShipY/ScaleFac*(scrnhight/2) + (scrnhight/2);
        LineTo(screenx,screeny); }

    }
    ElapsedT++;
    if (response != 'y') {
        printf("UX= %g  UY= %g \n",ShipUX,ShipUY);
        printf("ShipX= %g ShipY= %g\n\n",ShipX,ShipY); }
    }
}

```

BIBLIOGRAPHY

- Baker, Robert M. and Makemson, Maud W., An Introduction to Astrodynamics, Academic Press, Inc., London, 1960.
- Corbman, Bernard P., Textiles: Fiber to Fabric, McGraw-Hill Book Co., New York, 1983.
- Cornie, James A., et al., "Solidification Processing of Metal Matrix Composites", American Ceramic Society Bulletin, vol. 65, no. 2, 1986, pp. 293-297.
- Dieter, George, Engineering Design: A Materials and Processing Approach, McGraw-Hill Book Co., New York, 1983.
- Ely, Lawrence D., Return from Space, Charles C. Thomas, Springfield III, 1966.
- Gatenhaus, Solomon, Physics, Volume I, Holt, Rinehart, and Winston 1975.
- Goldsworthy, W. Brandt, "Composite Fibers and Matrices in Lunar Regolith", Space Studies Institute Newsletter, Vol XI, issue 5, Sept/Oct 85, pp 1-5.
- Hughes, William F. and Brighton, John A., Fluid Dynamics, Schaum's Outline Series, McGraw-Hill Book Co., New York, 1967.
- Jones, J.T. and Berard, M. F., Ceramics, Iowa State University Press, Ames, Iowa, 1972.
- Katz, Nathan R. and Leno, E.M., "Mechanical Behavior", Treatise on Materials Science and Technology, Academic Press, New York, 1976, pp. 241-262.
- Kober, J.F., "Filament Winding", Modern Plastics Encyclopedia 1984-1985, McGraw-Hill Book Co., New York, 1985, pp. 321-322.
- Levin, Ernest M., and Robbins, Carl R., and McGurdie, Howard F., Phase Diagrams for Ceramists, American Ceramic Society, Inc., Columbus, Ohio, 1964.

- Mutch, Thomas A., Geology of the Moon, Princeton University Press, Princeton, NJ, 1972.
- Nelson, walter C., and Loft, Ernest E., Space Mechanics, Prentice-Hall Inc., Englewood Cliffs, NJ, 1962.
- Pense, Alan W., and Brick, Robert M., and Gordon, Robert B., Structure and Properties of Engineering Materials, Fourth edition, McGraw-Hill Book Co., 1977.
- Raymer, John, "Filament Winding", Modern Plastics Encyclopedia 1983-1984, McGraw-Hill Book Co., New York, 1985, pp. 314-315.
- Scholes, Samuel R., Modern Glass Practice, CBI Publishing Co, Inc., Boston, 1974.
- Shigley and Mitchell, Mechanical engineering Design, Fourth Ed., McGraw-Hill Book Co., New York, 1983
- Steurer, Wolfgang H., "Materials for Thermal Protection", Materials for Missiles and Spacecraft, McGraw-Hill Book Co., Inc., New York, 1963, pp. 94-121.
- Tooley, Fay Van Isle, Handbook of Glass Manufacture, Second ed., Ashlee Publishing Co., New York, 1974.
- Van Vlack, Lawrence H., Elements of Material Science and Engineering, Fourth ed., Addison Wesley Publishing Co., 1980.
- Vaniman, D.T., and Papike, J.J., "Lunar Highland Melt Rocks:Chemistry Petrology, and Silicate Mineralogy", Proceedings of the Conference on the Lunar Highland Crust, Pergamon Press, Elmsford, NY, 1980, pp. 271-325.
- Vinh, Nguyen X., Busemann Adolf, Culp Robert D, Hypersonic and Planetary Entry Flight Mechanics, University of Michigan Press Ann Arbor, 1980.
- White, Frank M., Fluid Mechanics, McGraw-Hill Book Co., New York, 1979.

Miscellaneous

NASA Publication: Models of Earth's Atmosphere (90 to 2500 km), 1973

Babcock and Wilcox Company brochures concerning ceramic fiber products

Progress Report #1

Design of and Preliminary Manufacturing Specifications for
an Aero-Assisted Cargo Vehicle for Lunar Orbital to Earth
Orbital Transfer Missions

January 28, 1986

We found a copy of the ASME guidelines for research papers, so that we would have an idea of the organization of the paper.

We began a manual search for books and articles relating to the design topic.

Thanh Phan, a ME 4901 student, joined our design group.

We discussed objectives and specifications for our project, and began narrowing the topic.

We then set up further meeting dates for our group.

Progress Report #2

Design of and Preliminary Manufacturing Specifications for
an Aero-Assisted Cargo Vehicle for Lunar Orbital to Earth
Orbital Transfer Missions

February 4, 1986

We submitted our library search request and had the follow up interview on January 30. We are expecting the results back this week.

An interview was set up with the director of ATDC, Dr. Pentecost who is an expert on space shuttle tiles, to discuss possible materials for use in our design.

We used the material we have already found to narrow the design of the aero-brake down to one general shape. We then began to draw some rough sketches for use in further specification of the design.

We specified several topics for further research by different members of the group.

We discussed several possible materials to use in the design, in particular fiberglass cloth, but decided more research was necessary before any final decisions were made.

Team #11
Progress Report #3

Design of and Preliminary Manufacturing Specifications for an Aero-Assisted Cargo Vehicle for Lunar Orbital to Earth Orbital Transfer Missions

February 11, 1986

The results of the library search were received last week.

Scott made drawings of several aspects of the aerobrake, and blueprints were distributed to other members of the group.

A notebook was organized according to our outline so that we can begin organizing our material.

Katherine interviewed Dr. Pentecost concerning possible materials to be used. He offered several helpful ideas which the group will pursue.

Jeff and Thanh are in the process of organizing the aerodynamic and thermal data.

The group members plan to spend some time this week becoming familiar with the CAD/CAM system.

Team #11

Progress Report #9

Design of and Preliminary Manufacturing Specifications for an
Aero-Assisted Cargo Vehicle for Lunar Orbital to Earth Orbital
Transfer Missions

February 18, 1986

Thanh had a meeting with Dr. Roach of the AE department to discuss various methods for performing the aerodynamic analysis on the aero-brake.

Scott spent 7 hours learning how to use the CAD system. He also wrote a rough draft for the Abstract.

Jeff began writing some computer programs to calculate various values needed for the aerodynamic analysis.

Katherine found information on a material that looks promising for the shield as well as possible inclusion in the supporting structure. She is doing further research into this material.

We have all begun organizing tables, charts, and bibliographic material for the final report.

Team #11

Progress Report #5

Design of and Preliminary Manufacturing Specifications for an
Aero-Assisted Cargo Vehicle for Lunar Orbital to Earth Orbital
Transfer Missions

February 25, 1986

Thanh met with Dr. Flandro of the AE department to discuss various aerodynamic features of the design.

Scott has been working with the CAD system to modify the drawings.

Scott, Jeff, and Thanh have been working on thermal and aerodynamic numerical analysis. This analysis has been done on a superficial level to arrive at order of magnitude values for the structural design parameters.

Jeff and Thanh have been working on a computer program to refine this analysis.

The group has decided that a ceramic fiber textile should be used for the shield. Katherine is investigating several possible fiberglass manufacturing processes. She consulted another group in order to find out what materials will be mined on the moon.

Katherine has also found a ceramic-glass composite process that may be used to form the structure itself.

Katherine viewed the slides on the space shuttle in order to get any applicable information concerning the materials.

Team #11

Progress Report #6

Design of and Preliminary Manufacturing Specifications for an
Aero-Assisted Cargo Vehicle for Lunar Orbital to Earth Orbital
Transfer Missions

March 4, 1986

Katherine met with Dr. Benzel of the Ceramic Engineering Dept. to discuss possible composites for the structural elements, as well as the manufacturing techniques involved.

Scott has finished the CAD drawings as well as the structural analysis of the aero-brake.

Each group member is currently writing their particular sections of the final report.

Barring any further computer problems the computer simulation of the orbit is almost finished. When this is completed Than and Jeff will do the final thermodynamic analysis for the vehicle.

During our last meeting the final preparations for the written report were made, and various responsibilities were delegated.

DIALOG File 108: Aerospace - 82-86/Iss02

descent trajectories of the spacecraft from the orbit of the artificial Mars satellite are optimized. The principal types of optimal control laws under passive braking in the atmosphere are outlined, as well as the optimal control of the terminal state of the portion of the passive braking. (F.R.L.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *AERODYNAMIC BRAKES; *MARS LANDING; *OPTIMAL CONTROL; *SEQUENTIAL CONTROL; *TRAJECTORY OPTIMIZATION; CALCULUS OF VARIATIONS; DESCENT TRAJECTORIES; EQUATIONS OF MOTION; GRAVITATIONAL EFFECTS; MARS ATMOSPHERE; MARS SURFACE; MATHEMATICAL MODELS; NUMERICAL CONTROL; SOFT LANDING; SPACECRAFT MANEUVERS; TURNING FLIGHT

Subject Classification: 6531 .Space Vehicles (1965-74)

0651370 A74-24951

A wind-tunnel study of spinning conical disk decelerators at Mach 4

JAKUBOWSKI, A. K. (Virginia Polytechnic Institute and State University, Blacksburg, Va.)

Journal of Spacecraft and Rockets, vol. 11, Mar. 1974, p. 141-145. Research supported by the Virginia Polytechnic Institute and State University.

Publication Date: Mar. 1974 5 Refs.

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: JOURNAL ARTICLE

Most documents available from AIAA Technical Library

Journal Announcement: IAA7410

An experimental investigation was made of the aerodynamic torque and drag characteristics of several configurations of rotating conical disk models placed in a supersonic Mach 4 stream. A basic shape of 73-deg half angle was used and solid surface configurations as well as porous ones were tested. Experiments seem to indicate that at a given supersonic Mach number, the torque coefficient of a highly porous configuration can be approximately expressed as a function of a single variable parameter (Reynolds number related to the peripheral velocity) and two constants which depend on geometry of the disk. For a selected geometric configuration, torque coefficient is inversely proportional to the porosity of the surface. For solid surface disks, torque increases rapidly when grooves (or other deformations) are present which are oriented in the radial direction. Circumferential grooves or slots produce only a relatively small torque increase. (Author)

Descriptors: *AERODYNAMIC BRAKES; *CONICAL BODIES; *ROTATING DISKS; *SPIN DYNAMICS; *SUPERSONIC FLOW; *WIND TUNNEL TESTS; AERODYNAMIC DRAG; FLOW DISTRIBUTION; MACH NUMBER; POROUS WALLS; REYNOLDS NUMBER; TORQUE; WIND TUNNEL MODELS

Subject Classification: 6501 .Aerodynamics (1965-74)

0621687 N73-18827

Space tug aerobraking study. Volume 2: Technical (Aerobraking trajectory for return of reusable space tugs) Final Report

CORSO, C. J.; EVER, C. L.

Boeing Co., Huntsville, Ala. Saturn/Apollo/Skylab Div.

Corp. Source Code: BR177385

Publication Date: Apr. 1972 519P.

Report No.: NASA-CR-124057; D5-17142-VOL-2

Contract No.: NAS8-27501

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: REPORT

Most documents available from AIAA Technical Library

Other Availability: NTIS

Journal Announcement: STAR7309

The feasibility and practicality of employing an aerobraking trajectory for return of the reusable Space Tug from geosynchronous and other high energy missions was investigated. The aerobraking return trajectory modes from high orbits employ transfer ellipses which have low perigee altitudes wherein the earth's sensible atmosphere provides drag to reduce the Tug descent delta velocity requirements and thus decrease the required return trip propulsive energy. An aerobraked Space Tug, sized to the Space Shuttle payload capability and dimensional constraints, can accomplish 95 percent of the geosynchronous missions with a single Shuttle/Tug launch per mission. Aerodynamics, aerothermodynamics, trajectory, guidance and control, configuration concepts, materials, weights and performance parameters were identified. Sensitivities to trajectory uncertainties, atmospheric anomalies and re-entry environments were determined. New technology requirements and future studies required to further enhance the aerobraking potential were identified. (Author)

Descriptors: *AEROBRAKING; *AERODYNAMIC BRAKES; *REENTRY

TRAJECTORIES; *SPACE TUGS; RECOVERABLE SPACECRAFT; SPACE

SHUTTLES; TRANSFER ORBITS

Subject Classification: 6530 .Space Sciences (1965-74)

COSATI Code: 22A .Astronautics

0620164 N73-17266

The influence of aerodynamic decelerators on supersonic wakes: With an application of the gas hydraulic analogy (Performance prediction for deployable aerodynamic decelerators operating in supersonic wakes using gas dynamics analogy)

Final Technical Report, Apr. 1965 - Dec. 1969

BABISH, C. A., III

Air Force Flight Dynamics Lab., Wright-Patterson AFB, Ohio.

Corp. Source Code: AIO58438

Publication Date: Aug. 1972 105P.

Report No.: AD-751982; AFFDL-TR-72-54

Language: English

(cont. next page)

DIALOG File 108: Aerospace - 82-88/Iss02

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *AERODYNAMIC BRAKES; *DESCENT TRAJECTORIES;
*MARS LANDING; *RETROTHRUST; *THRUST PROGRAMMING; *TRAJECTORY
OPTIMIZATION; *ATMOSPHERIC ENTRY; *EQUATIONS OF MOTION; JET
CONTROL; LIFT DRAG RATIO; MARS ATMOSPHERE; SEQUENTIAL CONTROL
TERMINAL VELOCITY

Subject Classification: 7513 .Astrodynamics (1975-)

0689163 N74-28289

**Entrance corridors into the atmosphere of a planet with
execution of the spacecraft capture maneuver by aerodynamic
braking**

EYSMONT, N. A.

Scientific Translation Service, Santa Barbara, Calif.
Corp. Source Code: SE324499

In its Appl. Probl. of Space Ballistics (NASA-TT-F-15412) p
13-30 (SEE N74-28287 17-30)

Publication Date: Apr. 1974

Translation Note: Transl. into ENGLISH from the book
"Prikladnyye Zadachi Kosmicheskoy Ballistiki", Moscow, Nauka
Press, 1973 p 11-22

Language: English

Country of Origin: U.S.S.R. Country of Publication: United
States

Document Type: REPORT; TRANSLATION

Most documents available from AIAA Technical Library

Journal Announcement: STAR7417

The possibilities of spacecraft transfer from a pre-entrance
trajectory to a satellite orbit of a planet using aerodynamic
braking in the atmosphere of the planet are analyzed.
Available entrance corridors are determined depending on the
aerodynamic characteristics of the craft and the parameters of
the pre-entrance trajectories. Evaluations of the
possibilities of accomplishing the transfer maneuvers
depending on the errors in determining the pre-entrance
trajectory are given. (Author)

Descriptors: *AERODYNAMIC BRAKES; *PLANETARY ATMOSPHERES;
*SPACECRAFT MANEUVERS; ERRORS; TRAJECTORY ANALYSIS; TRANSFER
ORBITS

Subject Classification: 6530 .Space Sciences (1965-74)

COSATI Code: 22C .Spacecraft Trajectories & Reentry

0673217 N74-10034

**Lightweight, variable solidity knitted parachute fabric (for
aerodynamic decelerators)**

Patent

MATTHEWS, F. R., JR.; WHITE, E. C., Inventors (to NASA)
National Aeronautics and Space Administration. Langley
Research Center, Hampton, Va.

Corp. Source Code: ND210491

Publication Date: Oct. 1973

Announcements: Filed 23 Dec. 1971 Supersedes N72-21004 (10 -
12, p 1553) 6P.

Report No.: NASA-CASE-LAR-10776-1

Patent Info.: US-PATENT-3,764,097; US-PATENT-APPL-SN-211332

US-PATENT-CLASS-244-145

Language: English

Country of Origin: United States Country of Publication:
United States

Document Type: PATENT

Most documents available from AIAA Technical Library

Other Availability: US Patent Office

Journal Announcement: STAR7401

A parachute fabric for aerodynamic decelerator applications
is described. The fabric will permit deployment of the
decelerator at high altitudes and low density conditions. The
fabric consists of lightweight, highly open, circular knitted
parachute fabric with ribbon-like yarns to assist in air
deflection. (Official Gazette of the U.S. Patent Office)

Descriptors: *AERODYNAMIC BRAKES; *DRAG CHUTES; *PARACHUTE
FABRICS; EQUIPMENT SPECIFICATIONS; PATENTS; PRODUCT
DEVELOPMENT

Subject Classification: 6502 .Aircraft (1965-74)

COSATI Code: 11E .Fibers & Textiles

0668893 A74-42475

Payload recovery system for Centaure rocket

MAJEED, M. K. A. (Indian Space Research Organization, Vikram
Sarabhai Space Centre, Trivandrum, India)

In: International Symposium on Space Technology and Science,
10th, Tokyo, Japan, September 3-8, 1973, Proceedings.
(A74-42352 21-31) Tokyo, AGNE Publishing, Inc., 1973, p.
1163-1168.

Publication Date: 1973

Language: English

Country of Origin: India Country of Publication: Japan

Document Type: CONFERENCE PAPER

Journal Announcement: IAA7421

Description of the design, development, and flight testing
of a payload recovery system for a 300-mm-diam. two-stage
vehicle, Centaure. The payload is separated by a ball-type
mechanism at an altitude of 70 km, after the completion of the
scientific mission. During the down leg of the trajectory
metallic drag flaps are deployed. The stabilizer parachute
stabilizes the payload at an altitude of 8 km and performs the
aerodynamic braking. The main parachute is deployed at a
height of 4 km. Flotation gear is inflated at an altitude of 2
km to make the payload buoyant in the sea. ((Author))

Descriptors: *AERODYNAMIC BRAKES; *CENTAUR LAUNCH VEHICLE;
*FLIGHT STABILITY TESTS; *MULTISTAGE ROCKET VEHICLES;
*PAYLOADS; *RECOVERY PARACHUTES; FLIGHT PATHS; ROCKET FLIGHT;
SOUNDING ROCKETS; SYSTEMS ENGINEERING

Subject Classification: 6531 .Space Vehicles (1965-74)

0668476 A74-42058

**A variable drag drogue chute for use as the aerodynamic
decelerator in sailplanes**

BLONDER, G.

(cont. next page)

DIALOG File 108: Aerospace - 62-86/Iss02

0904944 A78-48229

Influence of slots on effectiveness of wing mechanization and control surfaces with separated flow

GULIAEV, V. V.; MIKHAILOV, A. A.; NISHT, M. I.
(Aviatsionnaia Tekhnika, vol. 20, no. 2, 1977, p. 119-121.)
Soviet Aeronautics, vol. 20, no. 2, 1977, p. 102-104.
Translation.

Publication Date: 1977

Language: English

Country of Publication: United States

Document Type: JOURNAL ARTICLE; TRANSLATION

Most documents available from AIAA Technical Library

Journal Announcement: IAA7821

(Previously cited in Issue 07, p. 1117, Accession no. A78-22647)

Descriptors: *AERODYNAMIC BRAKES; *AERODYNAMIC CHARACTERISTICS; *CONTROL SURFACES; *SEPARATED FLOW; *WING SLOTS; AERODYNAMIC FORCES; AIRCRAFT WAKES; LIFT; WING FLAPS
Subject Classification: 7502 .Aerodynamics (1975-)

0903731 A78-47016

The relative merits of aerodynamic and rocket braking for reentry vehicles at hypersonic speeds

WICK, B. H. (National Aerospace Laboratory, Tokyo, Japan); YOSHIKAWA, K. K.

In: International Symposium on Space Technology and Science, 12th, Tokyo, Japan, May 16-20, 1977, Proceedings. (A78-47001 21-12) Chofu, Tokyo, National Aerospace Laboratory, 1977, p. 121-126.

Publication Date: 1977

Language: English

Country of Origin: Japan Country of Publication: Japan

Document Type: CONFERENCE PAPER

Journal Announcement: IAA7821

Results are presented of a study of the relative merits of aerodynamic braking, and combined rocket and aerodynamic braking. The basis of comparison is the ratio of final to entry weight. The variables considered were heat of ablation of the heat shield, rocket specific impulse, vehicle weight-to-area ratio, vehicle nose radius, entry speed, and entry angle. ((Author))

Descriptors: *AERODYNAMIC BRAKES; *BRAKING; *HYPERSONIC REENTRY; *REENTRY VEHICLES; ABLATIVE MATERIALS; BLUNT BODIES; DECELERATION; GRAPHITE; REENTRY PHYSICS; REENTRY SHIELDING
Subject Classification: 7518 .Spacecraft Design, Testing & Performance (1975-)

0888603 A78-31886

Atmospheric braking to circularize an elliptical Venus orbit

MCRONALD, A. D.; NOCK, K. T. (California Institute of Technology, Jet Propulsion Laboratory, Pasadena, Calif.)
Jet Propulsion Lab., California Inst. of Tech., Pasadena.

Corp. Source Code: JUS74450

American Astronautical Society and American Institute of Aeronautics and Astronautics, Astrodynamics Specialist

Conference, Jackson Hole, Wyo., Sept. 7-9, 1977, Paper. 24 p.
Publication Date: Sep. 1977 8 Refs.
Contract No.: NAS7-100

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PAPER
Most documents available from AIAA Technical Library

Journal Announcement: IAA7812

The use of atmospheric drag to circularize an elliptical spacecraft orbit at Venus is analyzed parametrically for the Venus Orbital Imaging Radar Mission (VOIR) in 1983. Navigation, maneuver, and guidance requirements are discussed for the decay of a 24-hr orbit to a close circular orbit in about 30-60 days. A prototype 'Aerobrake' is described which is approximately 5 m in diameter and 25 kg in mass and which replaces a chemical retroengine of about 1300 kg in mass (delta V = 2.5 km/s) by a 700 kg in-orbit mass. The aerobrake, a light deployable Inconel sheet, shields the spacecraft from the flow and radiates the aerodynamic heating. ((Author))

Descriptors: *AERODYNAMIC BRAKES; *AERODYNAMIC DRAG; *CIRCULAR ORBITS; *ELLIPTICAL ORBITS; *VENUS (PLANET); ATTITUDE CONTROL; ENERGY REQUIREMENTS; HEAT SHIELDING; INCONEL (TRADEMARK); ORBIT DECAY; RADAR IMAGERY; SYNTHETIC ARRAYS
Subject Classification: 7513 .Astrodynamics (1975-)

0885780 A78-29063

Irrational flow about a spherical segment (aerodynamic brakes application)

Bezvikhnevoe obtekanie sfericheskogo segmenta

MALITS, P. IA.; TISHCHENKO, V. N. (Simferopol'skii Gosudarstvennyi Universitet, Simferopol, Ukrainian SSR)
Prikladnaia Mekhanika, vol. 14, Feb. 1978, p. 115-121. In Russian.

Publication Date: Feb. 1978 6 Refs.

Language: Russian

Country of Origin: U.S.S.R. Country of Publication: U.S.S.R.

Document Type: JOURNAL ARTICLE

Most documents available from AIAA Technical Library

Journal Announcement: IAA7811

The paper solves the problem of the potential flow of an ideal fluid which has moving in it a spherical surface with an arbitrary aperture-angle. A method for solving the singular integral equations of the problem is proposed, the solution being in the form of quadratures. Expressions of flow velocity on both sides of the moving surface are obtained for a variety of moving surfaces. The solution enables determination of the aerodynamic coefficients of such bodies. (B.J.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *AERODYNAMIC BRAKES; *FLOW VELOCITY; *POTENTIAL FLOW; *SPHERES; AERODYNAMIC COEFFICIENTS; FLOW DISTORTION; FLOW EQUATIONS; IDEAL FLUIDS; QUADRATURES; SINGULAR INTEGRAL EQUATIONS

Subject Classification: 7534 .Fluid Mechanics & Heat (cont. next page)

PRINTS

User: 002847 30Jan86 P002: PR 11/5/1-5
DIALOG (VERSION 2)

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Item 4 of 5

DIALOG File 108: Aerospace - 82-86/Iss02

1165040 A82-40291

A review of aeroassisted orbit transfer

WALBERG, G. D. (NASA, Langley Research Center, Hampton, VA)
National Aeronautics and Space Administration. Langley
Research Center, Hampton, Va.

Corp. Source Code: ND210491
American Institute of Aeronautics and Astronautics,
Atmospheric Flight Mechanics Conference, 9th, San Diego, CA,
Aug. 9-11, 1982, 24 p.

Publication Date: Aug. 1982 92 Refs.

Report No.: AIAA PAPER 82-1378

Language: English

Country of Origin: United States Country of Publication:
United States

Document Type: CONFERENCE PAPER

Most documents available from AIAA Technical Library

Journal Announcement: IA8220

The development of a theory of aeroassisted orbital plane
change maneuvers and necessary equipment is traced and an
assessment is made of potential applications. Synergetic plane
changes are effected through a combination of aerodynamic and
propulsive forces involving the dip of an orbiting vehicle
into the atmosphere, performance of an aerodynamic turn using
thrust if necessary, then reboosting into a reconfigured
orbit. The Orbiter is noted to possess large synergetic plane
change capability, and configurations of spacecraft such as
the Venus Orbiting Imaging radar for using aeroassist to brake
interplanetary velocities before establishing orbits are
described. Technology advances necessary to construct
effective aerobrake, aerocapture, and orbital transfer
vehicles are explored, including fabrication of inflatable
ballutes, lighter L/D configurations, and lifting brakes,
which are considered to be minor extensions of current
capabilities. (M.S.K.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *AEROASSIST; *ATMOSPHERIC ENTRY; *ORBITAL
MANEUVERS; *PLANETARY ORBITS; *TRANSFER ORBITS; *AERODYNAMIC
BRAKES; AEROMANEUVERING ORBIT TO ORBIT SHUTTLE; CAPTURE EFFECT
; ORBIT TRANSFER VEHICLES; TECHNOLOGY ASSESSMENT
Subject Classification: 7513 .Astrodynamics (1975-)

1081567 A81-20733

Flow field investigation of atmospheric braking for high drag vehicles with forward facing jets (in spacecraft entry)

GREINICH, A. F. (Boeing Co., Seattle, Wash.); WOODS, W. C.
(NASA, Langley Research Center, Hampton, Va.)
Boeing Co., Seattle, Wash.

Corp. Source Code: BR564481

American Institute of Aeronautics and Astronautics,
Aerospace Sciences Meeting, 19th, St. Louis, Mo., Jan. 12-15,
1981, 7 p.

Publication Date: Jan. 1981

Report No.: AIAA PAPER 81-0293

Language: English

Country of Origin: United States Country of Publication:
United States

5 Refs.

Document Type: CONFERENCE PAPER

Most documents available from AIAA Technical Library
Journal Announcement: IA8107

Flow field phenomena associated with a supersonic jet
issuing upstream into a hypervelocity flow field were
investigated experimentally in support of a new space vehicle
aerobreaking concept developed by Boeing for Orbital Transfer
Vehicles (OTV's). Tests were made on OTV models in the NASA
Langley 22 in. Mach 20 helium tunnel with jet exit Mach
numbers from 1.0 to 6.18 and ballute half angles of 45 and 60
deg. Force data were taken at zero angle of attack to
determine the effect of ballute angle, jet Mach number and jet
flow rate on vehicle drag. Bow shock structures were examined
in terms of flow steadiness to define acceptable jet flow rate
regimes for use in drag modulation. Limited tests were made to
obtain pressure and temperature distributions around the
ballute and to determine the ballute center of pressure. Test
results are presented and discussed relative to OTV
application and similar previous experimental investigations.
((Author))

Descriptors: *AERODYNAMIC BRAKES; *ATMOSPHERIC ENTRY; *FLOW
DISTRIBUTION; *JET EXHAUST; *SPACECRAFT REENTRY; *SUPERSONIC
DRAG; BALLUTES; BOW WAVES; ORBIT TRANSFER VEHICLES
Subject Classification: 7502 .Astrodynamics (1975-)

DIALOG File 108: Aerospace - 82-86/Iss02

1407462 N85-33177

A review of shock waves around aeroassisted orbital transfer vehicles

PARK, C.

National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

Corp. Source Code: NC473657

Publication Date: Jun. 1985 33P.

Report No.: NASA-TM-86769; REPT-85277; NAS 1.15:86769

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: REPORT

Most documents available from AIAA Technical Library

Other Availability: NTIS HC A03/MF A01

Journal Announcement: STAR8522

Aeroassisted orbital transfer vehicles (AOTVs) are a proposed type of reusable spacecraft that would be used to transport cargoes from one Earth-bound orbit to another. Such vehicles could be based on the proposed space station and used to transport commercial satellites from the space station to geostationary orbits or to polar orbits and return. During a mission, AOTVs would fly through Earth's atmosphere, thus generating aerodynamic forces that could be used for decelerating the vehicles or changing their direction. AOTV research findings were concerned with the shock-wave-induced, high-temperature airflows that would be produced around these vehicles during atmospheric flight. Special emphasis was placed on the problems of: (1) the chemical physics of multitemperature, ionizing, nonequilibrium air flows, and (2) the dynamics of the flows in the base region of a blunt body with complex afterbody geometry. (Author)

Descriptors: *AERODYNAMIC FORCES; *ATMOSPHERIC EFFECTS; *EARTH ATMOSPHERE; *ORBIT TRANSFER VEHICLES; *AERODYNAMIC BRAKES; ATMOSPHERIC ENTRY; HIGH TEMPERATURE; NONEQUILIBRIUM FLOW; SHOCK HEATING; SHOCK WAVES; SPACE STATIONS; SPACE TRANSPORTATION

Subject Classification: 7516 .Space Transportation (1975-)

COSATI Code: 22B .Spacecraft

1365788 A85-21826

A survey of aeroassisted orbit transfer

WALBERG, G. D. (NASA, Langley Research Center, Hampton, VA) National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

Corp. Source Code: ND210491

(American Institute of Aeronautics and Astronautics,

Atmospheric Flight Mechanics Conference, 9th, San Diego, CA, Aug. 9-11, 1982. AIAA Paper 82-1378

Rockets (ISSN 0022-4650). vol. 22, Jan.-Feb. 1985, p. 3-18. Previously cited in Issue 20, p. 3158, Accession no. A82-40291.

Publication Date: Feb. 1985 142 Refs.

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: JOURNAL ARTICLE; CONFERENCE PAPER
Most documents available from AIAA Technical Library
Journal Announcement: IAA8508

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *AEROASSIST; *ATMOSPHERIC ENTRY; *ORBITAL MANEUVERS; *PLANETARY ORBITS; *TRANSFER ORBITS; AERODYNAMIC BRAKES; AEROMANEUVERING ORBIT TO ORBIT SHUTTLE; CAPTURE EFFECT; ORBIT TRANSFER VEHICLES; TECHNOLOGY ASSESSMENT
Subject Classification: 7513 .Astrodynamics (1975-)

1278145 A84-15645

Space Shuttle/high energy upper stage capabilities for the 1990's

TEIXEIRA, C. (NASA, Johnson Space Center, Systems Integration Branch, Houston, TX)

National Aeronautics and Space Administration. Lyndon B. Johnson Space Center, Houston, Tex.

Corp. Source Code: ND052615

IN: NTC '82; National Telesystems Conference, Galveston, TX, November 7-10, 1982, Conference Record (A84-15623 04-32). New York, Institute of Electrical and Electronics Engineers, Inc., 1982, p. B3.4.1-B3.4.5.

Publication Date: 1982

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PAPER

Most documents available from AIAA Technical Library

Journal Announcement: IAA8404

Possible performance gains and cost reductions available through the evolution of succeeding larger unmanned, and then manned, orbital transfer vehicles (OTV) as Shuttle upper stages are projected. Future missions could include delivery of 10,000 lb to GEO, planetary missions in the 2000-12,000 lb class, 30-42 ft payloads in the 5000-10,000 lb class, and manned and unmanned satellite servicing by the turn of the century. The vehicles could evolve from the Centaur F vehicle through stages of all-propulsive configurations to aerobreaked, fully reusable vehicles. Reusability introduces cost savings and the ability to make plane changes. Furthermore, aerobreaking will double the payload capability for round trip journeys to GEO, bringing costs down to \$7000/lb. (M.S.K.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *COST REDUCTION; *ORBIT TRANSFER VEHICLES; *SPACE SHUTTLE PAYLOADS; *SPACE SHUTTLE UPPER STAGES; *SPACE SHUTTLES; *TECHNOLOGICAL FORECASTING; AERODYNAMIC BRAKES; CARGO SPACECRAFT; MISSION PLANNING; ORBITAL SERVICING; PAYLOAD DELIVERY (STS)

Subject Classification: 7516 .Space Transportation (1975-)

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